

DATA SHEET

AAT3620: Single Cell Li+ Switch Mode Battery Charger

Applications

- Digital camcorders
- Point of service (POS)
- Portable DVD players
- Portable hand-held solutions
- Portable media players

Features

- Input voltage range: 4.3 to 6.0 V
- Up to 2.0 A charging current capability
- 1.5 MHz PWM/linear charger
- Over 90% full rate charging efficiency
- Integrated switching device
- “No BAT” detect
- Safety timer
- Integrated sense resistor
- Built-in reverse blocking feature
- Battery preconditioning/constant-voltage/constant-current charging mode
- Programmable end-of-charging current
- 1% constant-voltage mode regulation
- Built-in programmable charging timer
- Charging current indication pin
- Over-voltage, over-current, and over-temperature protection
- Battery over-temperature protection
- Power-on reset and soft-start
- Space-saving TDFN (14-pin, 3 mm × 3 mm) package (MSL1, 260 °C per JEDEC J-STD-020)

Description

The BatteryManager™ AAT3620 is an ideal solution for charging high-capacity Li+ batteries. The AAT3620 can supply up to 2.0 A charging current with minimal thermal impact to mobile systems with features such as color display, camera with flash, organizer, video, etc., that requires battery capacity to keep pace with the power requirements.

The AAT3620 is a pulse-width modulation (PWM) switch mode/linear charger with high charging efficiency at the full constant-current (fast charge) rate. Based on a 1.5 MHz PWM step-down buck converter, the AAT3620 PWM switch mode controls the constant-current charging mode up to 2.0 A, and automatically switches to linear mode charging during the battery conditioning low level current and the light load end-of-charging current termination region. The full charging rate and the end-of-charging current can be programmed with separate external resistors. A shared charging current indication pin is available for a Coulomb counter.

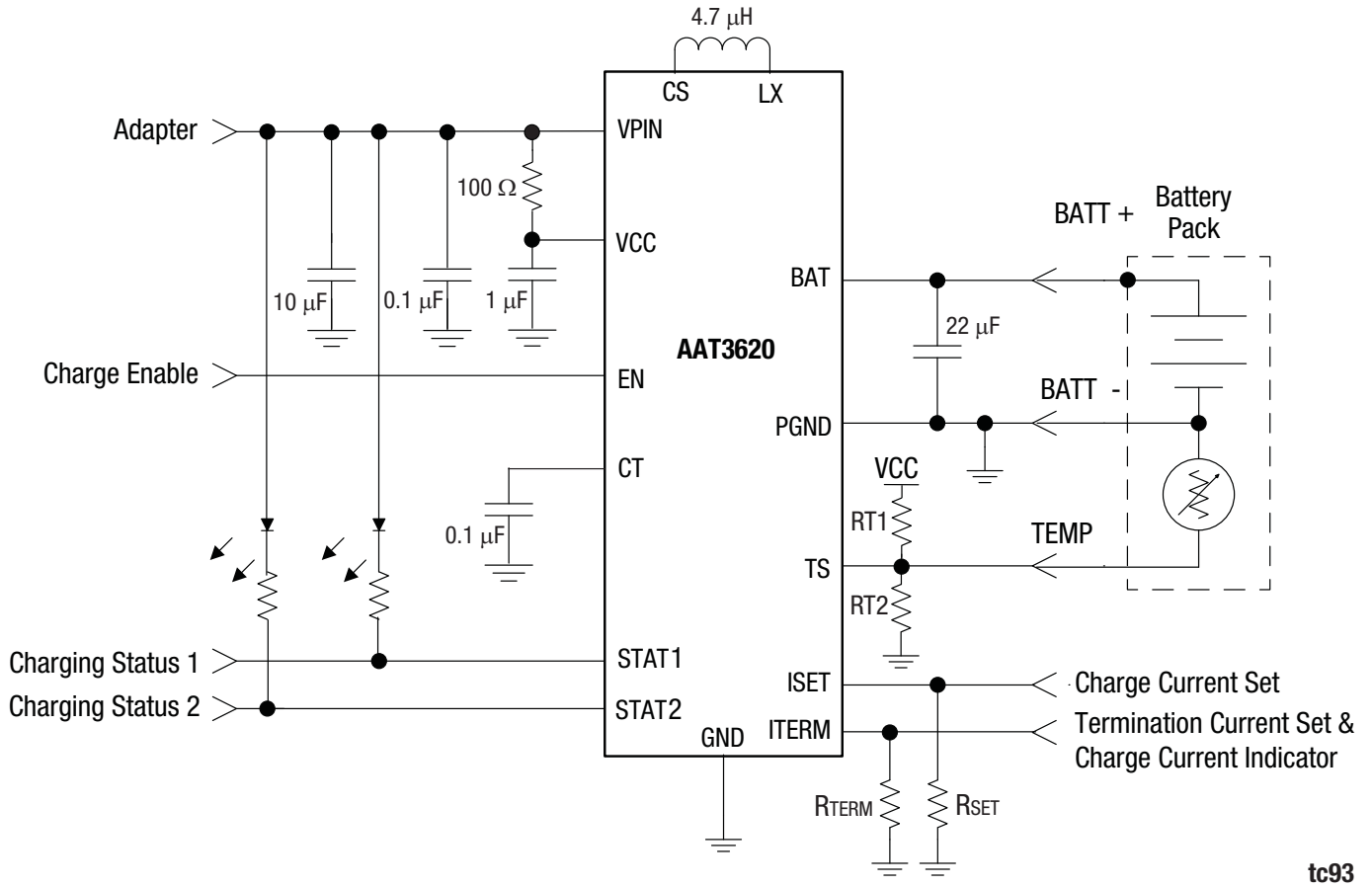
Battery charger temperature and charging state are fully monitored for fault conditions. In the event of an over-current, over-voltage, short-circuit or over-temperature failure, the device automatically shuts down. Two status monitor output pins are provided to indicate the battery charging status and power source status through two display LEDs. The AAT3620 also has a no-battery detection feature, "No BAT", which requires the safety timer.

The AAT3620 is available in a thermally enhanced, space-saving 14-pin, 3 mm × 3 mm TDFN package.

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.

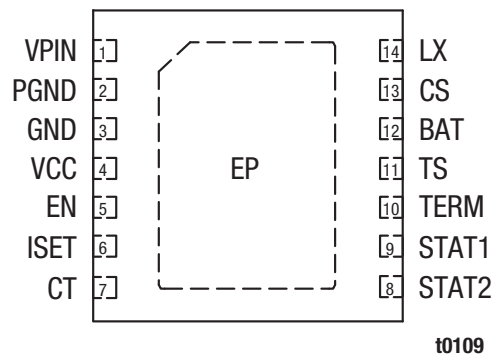


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Figure 1. AAT3620 Typical Application Circuit



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Figure 2. AAT3620 Pinout – 14-Pin, 3 mm x 3 mm TDFN (Top View)

Table 1. AAT3620 Signal Descriptions

| Pin # | Name | Type | Description |
|-------|-------|--------|--|
| 1 | VPIN | In | Adapter power input. |
| 2 | PGND | Ground | Power ground. |
| 3 | GND | Ground | Analog ground connection. |
| 4 | VCC | In | Supply Input. |
| 5 | EN | In | Charging enable input, active high, with internal pull-up (to VPIN). |
| 6 | ISET | In | Connect RSET resistor to pin to set constant-current charging current. |
| 7 | CT | In/Out | Timer pin. Connect timing capacitor here for charging timer function. |
| 8 | STAT2 | Out | Battery charging status 2 indicator pin to drive an LED, open-drain. |
| 9 | STAT1 | Out | Battery charging status 1 indicator pin to drive an LED, open-drain. |
| 10 | TERM | In/Out | Connect RTERM resistor to pin to set termination current. Charging current can be monitored with this pin. Leave OPEN to set to 200 mA default termination current. |
| 11 | TS | In/Out | Battery pack temperature sensing input. To disable TS function, pull up to Vcc through 10 kΩ resistor. |
| 12 | BAT | Out | Battery positive terminal connecting pin. |
| 13 | CS | In | Return pin for inductor for internal current sensing. |
| 14 | LX | In/Out | Switching node. |
| EP | EP | Ground | The exposed thermal pad (EP) must be connected to the board ground plane and pins 2 and 3. The ground plane should include a large exposed copper pad under the package for thermal dissipation (see package outline). |

Electrical and Mechanical Specifications

The absolute maximum ratings of the AAT3620 are provided in

Table 2, the thermal information is listed in Table 3, and electrical specifications are provided in Table 4.

Table 2. AAT3620 Absolute Maximum Ratings (Note 1)

| Parameter | Symbol | Minimum | Typical | Maximum | Units |
|--|--------|---------|---------|----------|-------|
| VPIN, LX | VP | -0.3 | | +6.5 | V |
| Other pins | VN | -0.3 | | VP + 0.3 | V |
| Operating junction temperature range | TJ | -40 | | + 150 | °C |
| Maximum power dissipation | Pd | | 2.5 | | W |
| 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 3. AAT3620 Thermal Information

| Parameter | Symbol | Value | Units |
|-------------------------------------|--------|-------|-------|
| Maximum thermal resistance (Note 1) | θJA | 50 | °C/W |
| Maximum power dissipation (Note 2) | Pd | 2 | W |

Note 1: Mounted on an FR4 board.

Note 2: Derate 2.7 mW/°C above 25 °C ambient temperature.

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.

Table 4. AAT3620 Electrical Specifications (1 of 2) (Note 1)
(VIN = 5.5 V, TA = -25 °C to +85°C, Unless Otherwise Noted, Typical Values are TA = 25 °C)

| Parameter | Symbol | Test Condition | Min | Typical | Max | Units |
|---|----------------------------|---|-------|--------------------------------------|------------------------|-----------|
| Operation | | | | | | |
| Adapter input voltage | VIN | | 4.3 | | 6.0 | V |
| Input under-voltage lockout | VCC_UVLO | V _{PIN} rising | 3.5 | | 4.3 | V |
| | | Hysteresis | | 150 | | V |
| Input sleep voltage | V _{IN_SLEEP} | No charging if V _{IN} < V _{IN_SLEEP} | | V _{BAT} + 0.05 | V _{BAT} + 0.2 | mV |
| Operating supply current | I _{VIN_OP} | EN = high, charging current = 200 mA | | | 5 | mA |
| Standby supply current | I _{VIN_STBY} | EN = high, no charge, power-saving mode | | | 2 | mA |
| Shutdown supply current | I _{VIN_SHDN} | EN = low, LX floating, sleep mode | | | 10 | µA |
| Forward leakage current, measured from LX to ground | I _{FWD_LKG} | EN = low, LX = 5.5 V | | | 1 | µA |
| Reverse leakage current, measured from LX to VIN | I _{REV_LKG} | EN = low or high, V _{IN} = 0 V, LX = 5.5 V | | | 1 | µA |
| BAT pin leakage current | I _{BAT_LKG} | V _{BAT} = 4.2 V, V _{IN} = 0 V or open | | | 1 | µA |
| Internal PMOS on resistance | R _{DS(ON)} | V _{IN} = 5.5 V | | 170 | 300 | mΩ |
| Internal NMOS on resistance | | V _{IN} = 5.5 V | | 120 | 250 | mΩ |
| PWM switching frequency | f _{SW} | V _{BAT} = 3.6 V, I _{CH_CC} = 1 A | 1.2 | 1.5 | 1.8 | MHz |
| Charging Regulation | | | | | | |
| Output charging voltage regulation | V _{BAT_REG} | | 4.158 | 4.2 | 4.242 | V |
| Charging soft-start delay | t _{SOFT_START} | Delay of charging from EN, or V _{CC_UVLO} , or V _{IN_ADPP} | | 100 | | µs |
| Battery conditioning battery voltage threshold | V _{BAT_BC} | Preconditioning battery charging when V _{BAT} rising: V _{BAT} < V _{BAT_BC} | 2.4 | 2.6 | 2.8 | V |
| Battery conditioning charging current | I _{CH_BC} | When V _{BAT} < V _{BAT_BC} | | 0.1 × I _{CH_CC} | | A |
| Typical battery conditioning charging current setting range | I _{CH_BC_TYP} | | 100 | | 200 | mA |
| Battery conditioning time- out | t _{CH_BC} | Stop charging if preconditioning time is more than t _{CH_BC} | -15% | 0.25 × C _{CT} | +15% | Minute/nF |
| Constant-current battery charging current accuracy | I _{CH_CC} | When V _{BAT_BC} < V _{BAT} < V _{BAT_REG} , 1 A to 2 A | -15% | I _{CH_CC} | +15% | % |
| Fast constant-current charging time out | t _{CH_CCTO} | Stop charging if fast charging time is more than t _{CH_CCFAST} | -15% | 0.022 × C _{CT} | +15% | Hour/nF |
| Constant voltage charging time-out | t _{CH_CVTO} | Stop charging if charging time is more than t _{CH_CV} | -15% | 0.03 × C _{CT} | +15% | Hour/nF |
| Battery recharging voltage threshold | V _{BAT_RCH} | If V _{BAT} falls below V _{BAT_RCH} , recharging starts | | V _{BAT_REG} - 0.1 | | V |
| Charging termination threshold current | I _{CH_TERM_TYP} | Terminate CV charging if I _{CH} < I _{CH_TERM} | | R _{TERM} × 10 ⁻⁶ | | A |
| Typical termination threshold current setting range | I _{CH_TERM_RANGE} | Charger termination current is clamped to the minimum or maximum value if set above or below the I _{TERM} range. | 50 | | 200 | mA |

Table 4. AAT3620 Electrical Specifications (2 of 2) (Note 1)
($V_{IN} = 5.5\text{ V}$, $T_A = -25\text{ }^\circ\text{C}$ to $+85\text{ }^\circ\text{C}$, Unless Otherwise Noted, Typical Values are $T_A = 25\text{ }^\circ\text{C}$)

| Parameter | Symbol | Test Condition | Min | Typical | Max | Units |
|---|----------------|---|------|----------------------|------|------------------|
| Logic and Status Input/Output | | | | | | |
| EN input high threshold | V_{IH} | | 1.6 | | | V |
| EN input low threshold | V_{IL} | | | | 0.4 | V |
| EN pin supply current | I_{EN} | EN = V_{IN} | | 0.1 | 1 | μA |
| | | EN = 0 V | | 0.6 | 10 | μA |
| STAT1, STAT2 pin leakage current | I_{SLEAK} | When output FET is off | | | 1 | μA |
| STAT1 and STAT2 pin current sink capability | I_{STATX} | | | | 10 | mA |
| STAT pulse width | tSTAT_PULSE | In fault conditions: CCT = 100 nF | | 0.5 | | s |
| STAT pulse frequency | fSTAT_FLASH | In fault conditions: CCT = 100 nF | | 1 | | Hz |
| Protection | | | | | | |
| Battery over-voltage protection threshold | V_{BAT_OVP} | No charging if $V_{BAT} > V_{BAT_OVP}$ | | $V_{BAT_REG} + 0.2$ | | V |
| Over-current protection threshold and limit | I_{CL} | | 2.46 | 3.0 | 4.0 | A |
| TS hot temperature fault | V_{TS1} | Threshold V_{TS} falling | 29.1 | 30 | 30.9 | % V_{CC} |
| | | Hysteresis | | 50 | | mV |
| TS cold temperature fault threshold | V_{TS2} | Threshold V_{TS} rising | 58.2 | 60 | 61.8 | % V_{CC} |
| | | Hysteresis | | 50 | | mV |
| Thermal shutdown | TSD | | | 140 | | $^\circ\text{C}$ |
| Thermal shutdown hysteresis | TSD_HYS | | | 15 | | $^\circ\text{C}$ |

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

Typical Performance Characteristics

Typical performance characteristics of the AAT3620 are illustrated in Figures 3 through 10.

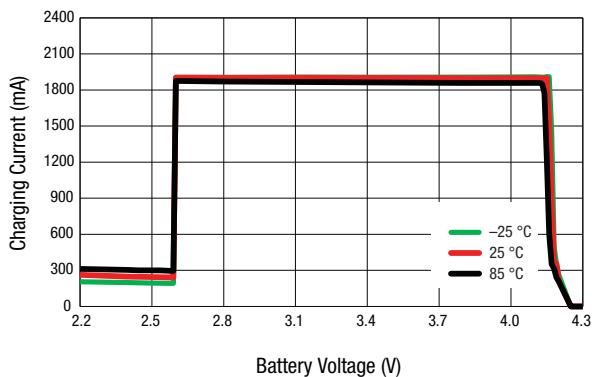


Figure 3. Charging Current vs Battery Voltage

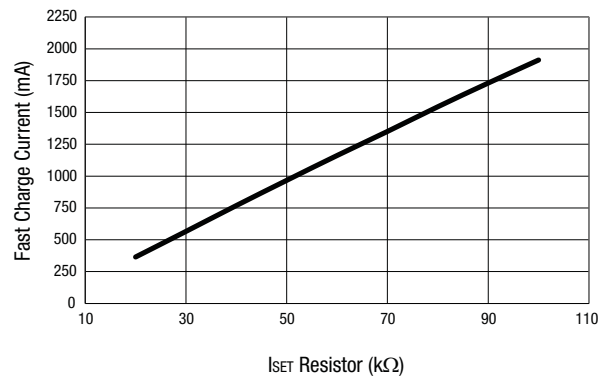


Figure 4. Constant-Current Charging Mode Current vs ISET Resistor ($V_{IN} = 5\text{ V}$, $V_{BAT} = 3.5\text{ V}$)

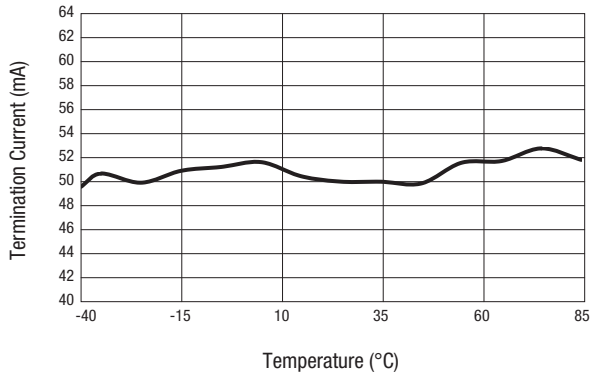


Figure 5. Termination Current vs Temperature
($V_{IN} = 5\text{ V}$, $R_{TERM} = 49.9\text{ k}\Omega$)

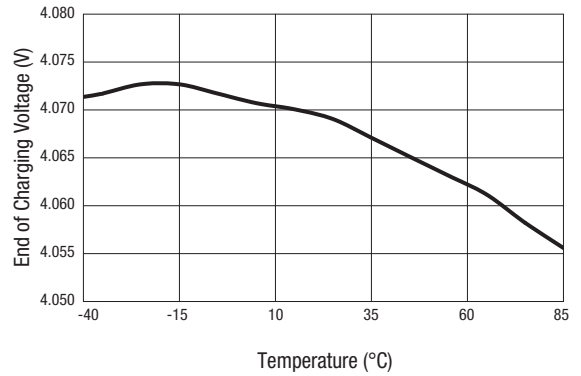


Figure 6. Recharging Voltage vs Temperature
($V_{IN} = 5\text{ V}$)

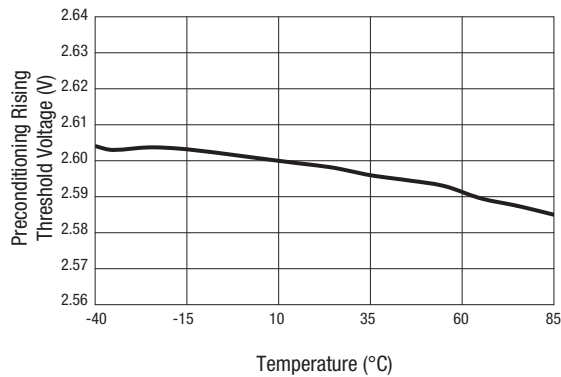


Figure 7. Preconditioning Rising Threshold Voltage vs Temperature
($V_{IN} = 5.5\text{ V}$)

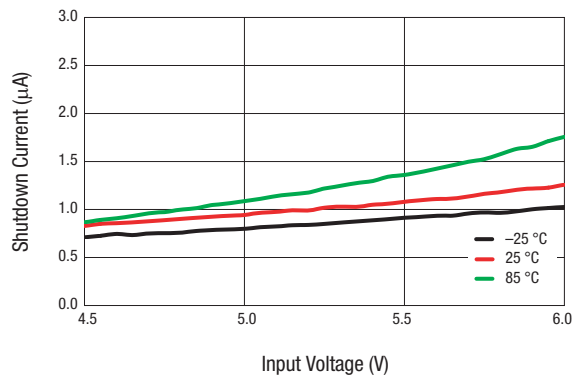


Figure 8. Shutdown Current vs Input Voltage

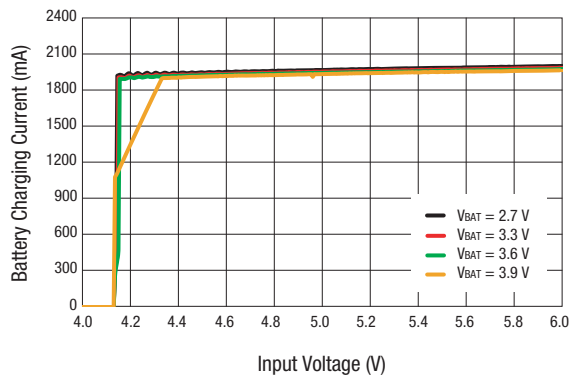


Figure 9. Charging Current vs Input Voltage ($T = -25\text{ }^\circ\text{C}$)

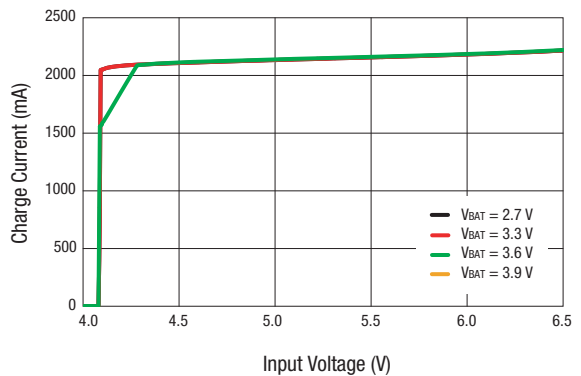


Figure 10. Charging Current vs Input Voltage ($T = 85\text{ }^\circ\text{C}$)

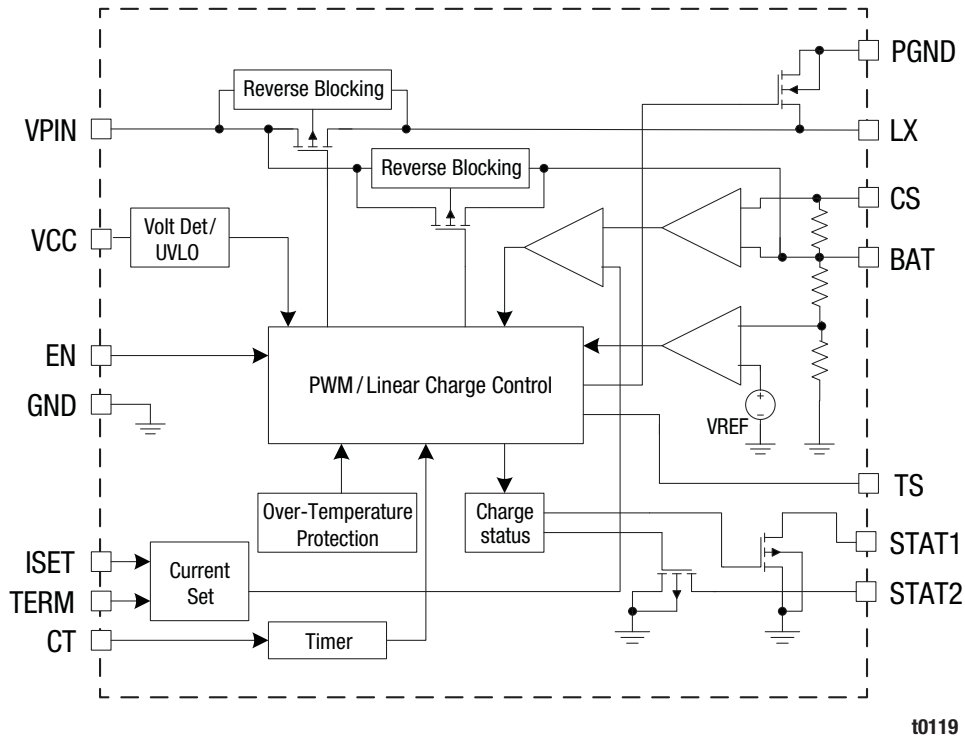


Figure 11. AAT3620 Functional Block Diagram

Functional Description

Control Loop

The AAT3620 uses an average current mode step-down converter to implement the DC-DC switch-mode converter function during constant-current mode charging. The technique of average current mode control overcomes peak current control problems by introducing a high gain integrating current error amplifier into the current loop. Average current tracks the sensed output current with a high degree of accuracy and excellent noise immunity. The oscillator sawtooth ramp provides compensation so no slope compensation is required for duty cycle exceeding 50%. The high gain of the current error amplifier at DC accurately programs the output. The switching charger works in continuous current mode PWM only. There is a soft start before entering constant-current charging mode and the charger re-enters linear operation in constant voltage mode when the charging current drops below 300 mA.

A functional block diagram is shown in Figure 11.

Linear vs Switching Battery Charging

The AAT3620 performs battery charging using the benefits of the step-down or buck architecture to multiply the input current when stepping down the output voltage. This property maximizes battery charging from current limited devices and greatly decreases power and heat-related dissipation. The process is expressed mathematically in the following comparison:

Linear Charging

Linear charging current relationship:

$$I_{BATL} = I_{IN}$$

Efficiency of linear charger:

$$\eta = \frac{V_{BAT}}{V_{IN}}$$

Switch-Mode Charging

Switch-mode current relationship:

$$I_{BATS} = \frac{\eta_s \times V_{IN} \times I_{IN}}{V_{BAT}}$$

Where: $\eta_s = 90\%$.

Example: Power Savings

Conventional linear charger IC:

$$P_D = (V_{IN} - V_{BAT}) \times I_{BAT} = (5 - 3.5) \times 0.5 = 0.75W$$

Switch-mode charger IC:

$$P_D = \frac{V_{BAT} \times I_{BAT}}{\eta} - V_{BAT} \times I_{BAT} = \frac{3.5 \times 0.5}{0.9} - (3.5 \times 0.5) = 0.194W$$

Adapter Input Charging Inhibit and Resume

The AAT3620 has a UVLO and power-on reset feature so that if the input supply to the ADP pin drops below the UVLO threshold, the charger suspends charging and shuts down. When power is re-applied to the IN pin or the UVLO condition recovers, the system charging control assesses the state of charging on the battery cell and automatically resumes charging in the appropriate mode for the condition of the battery.

Input/Output Capacitor and Inductor

The AAT3620 contains a high-performance 2 A, 1.5 MHz synchronous step-down converter. The step-down converter operates to ensure high efficiency performance over all load conditions. It requires only 3 external power components (C_{IN}, C_{OUT}, and L).

Apart from the input capacitor, only a small L-C filter is required at the output side for the step-down converter to operate properly. Typically, a 4.7 μH inductor such as the Würth 7447789004 and a 22 μF to 47 μF ceramic output capacitor is recommended for low output voltage ripple and small component size. Ceramic capacitors with X5R or X7R dielectrics are highly recommended because of their low ESR and small temperature coefficients. A 10 μF ceramic input capacitor is sufficient for most applications.

Battery Charging

Battery charging starts only after the AAT3620 checks several conditions to maintain a safe charging environment. The input supply must be above the minimum operating voltage (UVLO) and above the battery voltage by 0.3 V, the battery temperature must be within the 0 °C ~ 45 °C range, and the enable pin must be high.

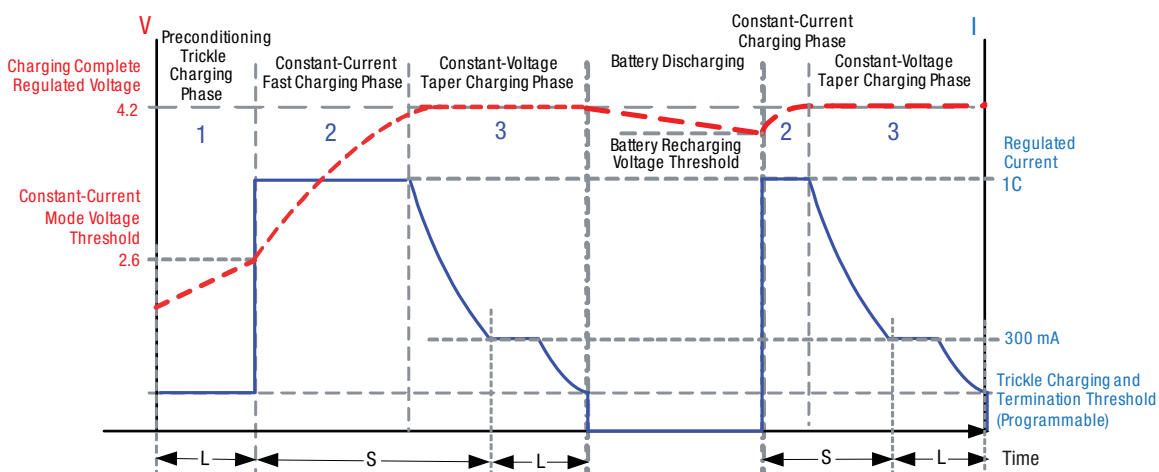
The AAT3620 checks the condition of the battery and determines which charging mode to apply. If the battery voltage is below V_{BAT_BC}, the AAT3620 begins battery conditioning until the battery voltage reaches V_{BAT_BC}. The battery conditioning current is 10% of constant-current level. Once the AAT3620 reaches V_{BAT_BC}, it begins constant-current mode charging. The constant-current mode current level is programmed using a single resistor from the ISET pin to ground. Programmed current can be set from a minimum of 1 A to a maximum of 2 A. Constant-current charging continues until the battery voltage reaches the voltage regulation point V_{BAT_REG}. When the battery voltage reaches V_{BAT_REG}, the AAT3620 transitions to constant-voltage mode. The regulation voltage is factory programmed to a nominal 4.2 V and continues charging until the charging current is reduced to the termination current programmed by the resistor connected from ITERM to ground. The termination current program range is 50 to 200 mA.

After the charging cycle is complete, the AAT3620, turns off the series pass device and automatically goes into a power saving mode. During this time, the series pass device blocks current in both directions, preventing the battery from discharging through the IC.

The AAT3620 shuts down if the charger source is disconnected until the charging source is reconnected and V_{IN} is greater than the V_{IN_SLEEP} threshold.

Figure 12 illustrates the entire battery charging profile, which consists of three phases:

1. Preconditioning-current mode (trickle) charging
2. Constant-current mode charging
3. Constant-voltage mode charging



The profile consists of three phases:
 1. Preconditioning-Current Mode (Trickle) Charging - Linear Mode
 2. Constant-Current (Fast) Mode Charging - Switching Mode
 3. Constant-Voltage Mode (Taper) Charging - Switching/Linear Mode.

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Figure 12. Charging Current and Battery Voltage vs Time

The battery preconditioning current is equal to 10% of the constant-current charging level, so the battery preconditioning current range is 100 to 200 mA. Linear mode is on standby while switch-mode is active in the constant-current charging region $2.6\text{ V} < V_{BAT} < 4.2\text{ V}$. The charger re-enters linear mode while in constant voltage mode after the switch-mode current drops below 300 mA. The termination current is programmed by an external resistor with a separate ITERM pin and the termination current set pin also monitors the charging current. The output short circuit current is equal to the battery preconditioning current.

Preconditioning Trickle Charge

Battery charging starts only after the AAT3620 battery charger checks several conditions in order to maintain a safe charging environment. The system operation flow chart for the battery charger operation is shown in Figure 13. The input supply must be above the minimum operating voltage (UVLO) and the enable pin (EN) must be high (it is internally pulled up). When the battery is connected to the BAT pin, the battery charger checks the condition of the battery and determines which charging mode to apply.

Preconditioning – Current Mode Charging Current

If the battery voltage is below the preconditioning voltage threshold V_{CH_BC} , the battery charger initiates precondition trickle charging mode and charges the battery at 10% of the programmed constant-current magnitude. For example, if the programmed current is 1 A, the trickle charging current would be 100 mA. Trickle charging is a safety precaution for a deeply discharged cell. It also reduces the power dissipation in the internal series pass MOSFET when the input-output voltage differential is at its highest.

Constant – Current Mode Charging Current

Trickle charging continues until the battery voltage reaches V_{BAT_BC} . At this point the battery charger begins constant-current charging. The current level default for this mode is programmed using a resistor from the ISET pin to ground. Programmed current can be set at a minimum of 100 mA and up to a maximum of 2.0 A.

The AAT3620 contains a high performance 2 A, 1.5 MHz synchronous step-down converter. The step-down converter operates to ensure high efficiency performance over all load conditions. It requires only 3 external power components (C_{IN} , C_{OUT} , and L).

Constant – Voltage Mode Charging

Constant-current charging continues until the battery voltage reaches the output charging voltage regulation point V_{BAT_REG} . When the battery voltage reaches V_{BAT_REG} , the battery charger transitions to constant-voltage mode. V_{BAT_REG} is factory programmed to 4.2 V (nominal). Charging in constant-voltage mode continues until the charging current is reduced to the programmed end-of-charging termination current.

Power-Save Mode

After the charging cycle is complete, the battery charger turns off the series pass device and automatically goes into power-save mode. During this time, the series pass device blocks current in both directions to prevent the battery from discharging through the battery charger. In power-save mode, the battery charger monitors all parameters and resumes charging in the most appropriate mode.

Sleep Mode

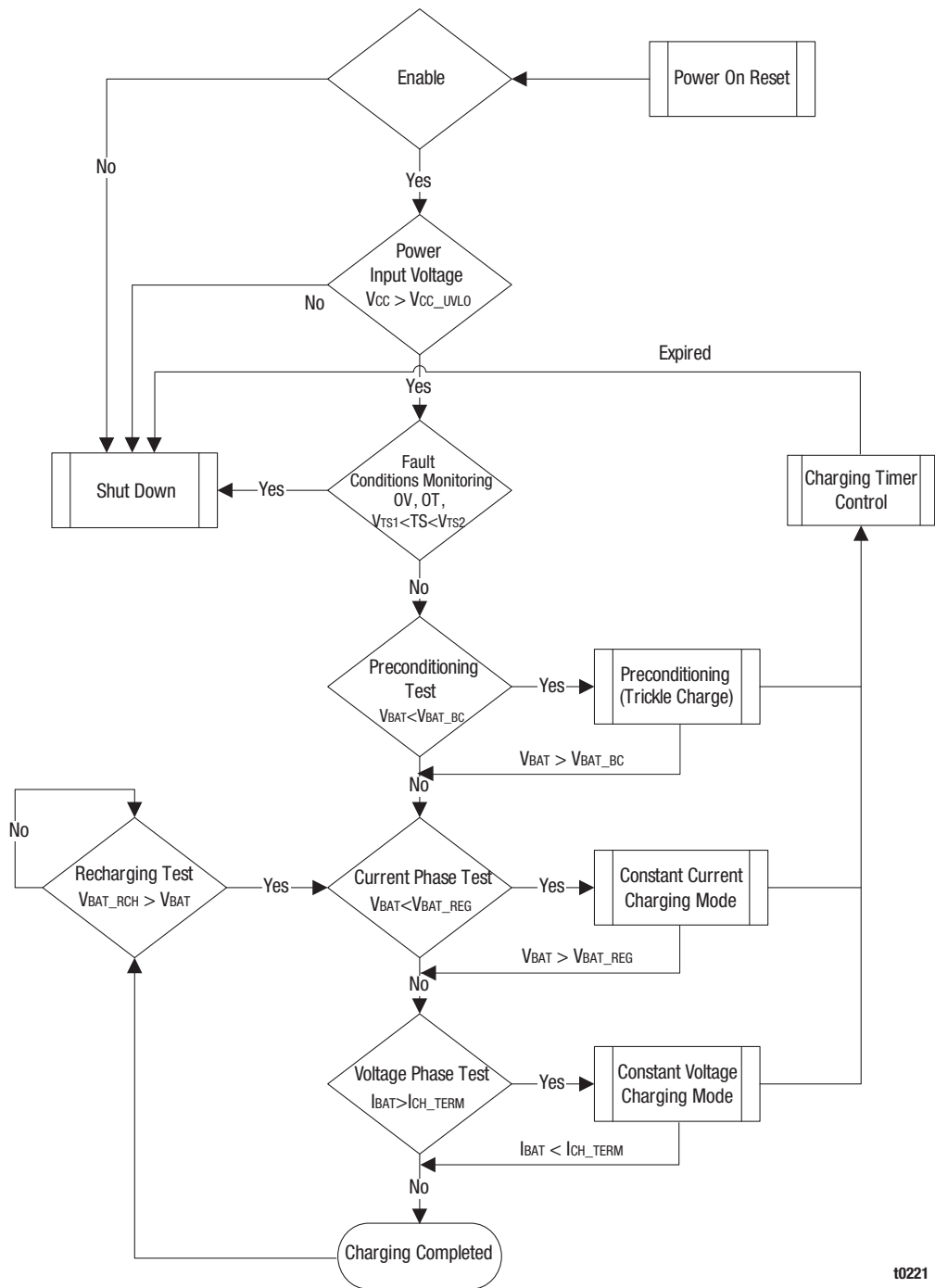
The battery charger shuts down if the charger source is disconnected and V_{IN} is less than V_{IN_SLEEP} threshold. It comes out of sleep mode if either V_{IN} is greater than V_{IN_SLEEP} or EN pin is cycled high while V_{IN} is greater than V_{IN_SLEEP} .

Programming Charging Current (ISET)

The default constant-current mode charging level is user-programmed with a set resistor placed between the ISET pin and ground. The accuracy of the constant charging current, as well as the preconditioning trickle charging current, is dominated by the tolerance of the set resistor. For this reason, a 1% tolerance metal film resistor is recommended for the set resistor function. The constant charging current levels from 1 to 2 A can be set by selecting the appropriate resistor value from Table 5.

Table 5. ISET Resistor vs Constant-Current Mode Current

| RSET (kΩ) | ICH_CC (mA) |
|-----------|-------------|
| 100 | 2000 |
| 90 | 1800 |
| 80 | 1600 |
| 70 | 1400 |
| 60 | 1200 |
| 50 | 1000 |
| 40 | 800 |
| 30 | 600 |
| 20 | 400 |



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Figure 13. System Operation Flowchart for the Battery Charger

Programmable Charging Termination Current

The charging termination current I_{CH_TERM} can be programmed by connecting a resistor from TERM to GND:

$$I_{CH_TERM} = R_{TERM} \times 10^{-6}$$

If the TERM pin is left open, the termination current level is set to 200 mA as the default.

When the charging current drops to the termination current level, the device terminates charging and goes into a power-save mode. The charger remains in this mode until the battery voltage decreases to a level below the battery recharging voltage threshold (VBAT_RCH).

Consuming very low current in the power-save mode, the AAT3620 minimizes battery drain when it is not charging. This feature is particularly useful in applications where the input supply level can fall below the battery charge. If the AAT3620 input voltage drops, the device enters sleep mode and automatically resumes charging once the input supply has recovered from the fault condition.

The TERM pin can also be used as a charging current monitor when the charging current voltage level = 1 A/V.

Status Indicator (STAT1/STAT2)

Charging Status Output

The AAT3620 provides battery charger status using two status pins (STAT1 and STAT2). Each of the two pins is internally connected to an N-channel open-drain MOSFET. The status pin can indicate the conditions shown in Table 6.

The LEDs 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 STAT pins. LED current consumption adds to the overall thermal power budget for the device package, so keeping the LED drive current to a minimum is recommended – 2 mA should be sufficient to drive most low-cost green or red LEDs. Do not exceed 8 mA for driving an individual status LED. The required ballast resistor values can be estimated using the following equation:

$$R_{BALLSAT} = \frac{V_{IN} - V_{F(LED)}}{I_{LED}}$$

Example:

$$R_{BALLSAT} = \frac{5.0V - 2.0V}{2mA} = 1.5k\Omega$$

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

Protection Circuitry

Charging Safety Timer (CT)

While monitoring the charging cycle, the AAT3620 utilizes a charging safety timer to help identify damaged cells and to ensure that the cell is charged safely:

- Upon initiating a charging cycle, the AAT3620 charges the cell at 10% of the programmed maximum charging until VBAT > 2.6 V.
- If the cell voltage fails to reach the precondition threshold of 2.6 V (typical) before the safety timer expires, the cell is assumed to be damaged and the charging cycle terminates.
- If the cell voltage exceeds 2.6 V prior to the expiration of the timer, the charging cycle proceeds into fast charging.

There are three time-out periods, as shown in Table 7.

Table 6. LED Status Indicator STAT1 and STAT2

| Conditions | STAT1 | STAT2 |
|--|-----------------------|-----------------------|
| Pre-charging | ON | ON |
| Fast-charging | ON | OFF |
| End-of-charging (charging complete) | OFF | ON |
| Charging disabled | OFF | OFF |
| Sleep mode (VIN < VIN_SLEEP) | OFF | OFF |
| No battery with charging enabled | FLASH, 50% duty cycle | FLASH, 50% duty cycle |
| Fault condition (battery 0 V) | OFF | OFF |
| Fault condition [battery OT (over-temperature) / UT (under-temperature)] | OFF | OFF |
| Fault condition (device OT) | OFF | OFF |
| Fault (pre-charging time out) | OFF | FLASH, 50% duty cycle |
| Fault (time out) | OFF | OFF |

Table 7. Summary for a 0.1 μF Ceramic Capacitor Used for the Timing Capacitor

| Mode | Time |
|---|------------|
| Trickle charging (TC) time-out | 25 minutes |
| Trickle charging (TC) + constant-current (CC) mode time-out | 2.2 hours |
| Constant-voltage (CV) mode time-out | 3 hours |

The AAT3620 has a battery fault detector, which, when used in conjunction with a 0.1 μF capacitor on the CT pin, outputs a 1 Hz signal with 50% duty cycle at the STAT2 pin in the event of a time-out while in trickle charging mode.

The CT pin is driven by a constant-current source and provides a linear response to increase the timing capacitor value. Thus, if the timing capacitor is doubled from the nominal 0.1 μF value, the time-out periods are doubled.

The CT pin should not be left floating or unterminated, as this would cause errors in the internal timing control circuit. The constant-current provided to charge the timing capacitor is very small, so this pin is susceptible to noise and changes in capacitance value. Therefore, the timing capacitor should be physically located on the printed circuit board layout as close as possible to the CT pin. Because the accuracy of the internal timer is dominated by the capacitance value, a ceramic capacitor with 10% tolerance or better is recommended. The X7R and X5R types of ceramic capacitors are good choices for this application.

The AAT3620 has the no-battery detection function, "No-BAT". The CT pin capacitor (C_{CT}) sets up an internal clock to reset the no battery detector every 8 clock periods. The internal clock frequency is inversely proportional to the C_{CT}:

$$f = \frac{100nF \times Hz}{C_{CT}}$$

The no-battery detection function detects when the charger toggles between charging termination and the recharging threshold in less than 8 clock periods. If this occurs for four consecutive times, the battery is considered disconnected. Requiring four consecutive "No BAT" cycles prevents a false indication when the battery connection is bounced. If the battery is disconnected while powered on, the recommended 0.1 μF capacitor at CT pin creates a 1 Hz internal clock to make the STAT LED blink at 1 Hz, 50% duty cycle, to indicate "no battery connected."

To ensure that the charger cycles between charging termination and recharging in less than 8 clock periods, the BAT pin capacitor cannot exceed 22 μF for every 100 nF on the CT pin. For example, if C_{CT} is 220 nF, the capacitor on the BAT pin cannot exceed 47 μF. If more capacitance is used on the BAT pin, it takes longer than 8 clock periods to complete a charge termination/recharging cycle and the no-battery detection does not work.

Note that disabling the safety timer (CT pin grounded) on the AAT3620 leads to a false "No BAT" detection, and both STAT pins go low after four consecutive charge termination/recharge cycles.

Over-Voltage Protection

An over-voltage event is defined as a condition where the voltage on the BAT pin exceeds the maximum battery charging voltage and is set by the over-voltage protection threshold (V_{BAT_OVP}). If an over-voltage condition occurs, the AAT3620 charging control shuts down the device until the voltage on the BAT pin drops below V_{BAT_OVP}. The AAT3620 resumes normal charging operation after the over-voltage condition is removed. During an over-voltage event, the STAT LEDs report a system fault.

Over-Temperature Shutdown

The AAT3620 has a thermal protection control circuit which shuts down charging functions if the internal die temperature exceeds the preset thermal limit threshold. When the internal die temperature falls back below the thermal limit, normal operation resumes the previous charging state.

Battery Temperature Fault Monitoring (TS)

In the event of a battery over-temperature condition, the charging control turns off the internal pass device and reports a battery temperature fault on the STAT pins. After the system recovers from a temperature fault, the device resumes charging operation. The AAT3620 checks battery temperature before starting the charging cycle, as well as during all stages of charging. This is accomplished by monitoring the voltage at the TS pin. The internal battery temperature sensing system (Figure 14) is comprised of two comparators that establish a voltage window for safe operation. The thresholds for the TS operating window are bounded by the V_{TS1} and V_{TS2} specifications. Refer to the electrical characteristics in Table 4: V_{TS1} threshold = 0.30 × V_{CC} and the V_{TS2} threshold = 0.60 × V_{CC}.

This system is intended for use with negative temperature coefficient thermistors (NTC), which are typically integrated into the battery package. Most of the commonly used NTC thermistors in battery packs are approximately 10 kΩ at room temperature (25 °C). If the battery gets too hot during charging due to an internal fault or excessive constant charging current, the thermistor heats up and reduces in value, pulling the TS pin voltage lower than the TS1 threshold, and the AAT3620 stops charging until the condition is removed, when charging is resumed.

To accurately set the TS voltage according to the temperature coefficient and the nominal value of the thermistor, two resistors can be used as shown in the example below. It is recommended to use NTC thermistors in the 10 kΩ to 100 kΩ range, with Beta constant values in the 3000 to 5000 range.

$$RT2 = \frac{R_{NTC(HOT)} \times R_{NTC(COLD)} \times \left(\frac{1}{Ratio\ Cold} - \frac{1}{Ratio\ Hot} \right)}{R_{NTC(HOT)} \times \left(\frac{1}{Ratio\ Hot} - 1 \right) - R_{NTC(COLD)} \times \left(\frac{1}{Ratio\ Cold} - 1 \right)} (\Omega)$$

$$RT1 = \left(\frac{1 - Ratio\ Cold}{Ratio\ Cold} - \frac{RT2 \times R_{NTC(COLD)}}{RT2 + R_{NTC(COLD)}} \right) (\Omega)$$

Where:

Ratio Cold = 0.60 (2% tolerance)

Ratio Hot = 0.30 (2% tolerance)

RNTC(COLD) = Thermistor resistance at Cold (typically 0 °C)

RNTC(HOT) = Thermistor resistance at Hot (typically 45 °C)

For a 10 kΩ NTC thermistor with a Beta of 3370:

RNTC(0°C) = 28.1 kΩ

RNTC(45°C) = 4.91 kΩ

The calculation results are as follows:

RT2 = 31.6 kΩ

RT1 = 9.92 kΩ

If the use of the TS pin function is not required by the system, it should be tied to VCC using a 10 kΩ resistor.

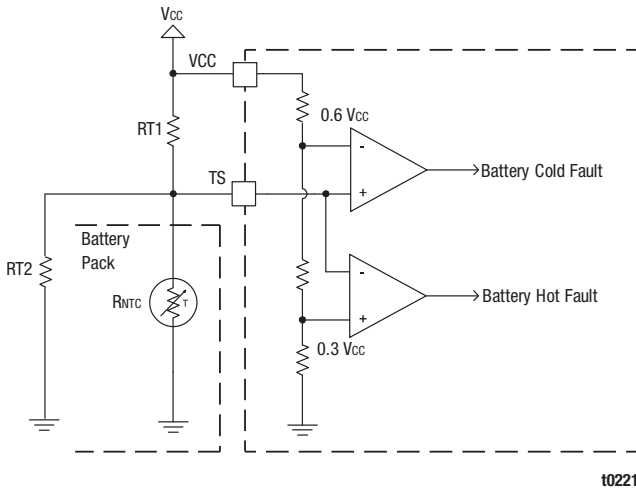


Figure 14. AAT3620 Battery Temperature Sense Circuit

Thermal Considerations

The actual maximum charging current is a function of Charging Adapter input voltage, the state of the battery charging at the moment of charging, the system supply current from the BAT pin, the ambient temperature and the thermal impedance of the package. The maximum programmable current may not be achievable under all operating parameters.

The AAT3620 is offered in a TDFN33-14 package which can provide up to 2 W of power dissipation when properly bonded to a printed circuit board. The maximum thermal resistance is 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 also has 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 considerations:

1. The maximum power dissipation for a given situation should be calculated:

$$P_{D(MAX)} = \frac{T_{J(MAX)} - T_A}{\theta_{JA}}$$

Where:

PD(MAX) = maximum power dissipation (W)

θJA = package thermal resistance (°C/W)

TJ(MAX) = maximum device thermal shutdown temperature (°C) [140 °C]

TA = ambient temperature (°C)

2. The power dissipation for both the linear charging mode and the switching charger mode should be considered.

The power dissipation for the switching charger can be calculated by the following equation:

$$P_{D(MAX)} = \frac{I_{CH_CC}^2 \times [R_{DS(ON)HS} \times V_{BAT} + R_{DS(ON)LS} \times (V_{PIN} - V_{BAT})]}{V_{PIN}} + (t_{SW} \times f_{SW} \times I_{CH_CC} + I_{QOP}) \times V_{PIN}$$

Where:

PD(MAX) = total power dissipation by the device

VPIN = adapter input voltage

VBAT = battery voltage at the BAT pin

ICH_CC = constant charging current programmed for the application

IQOP = quiescent current consumed by the IC for normal operation [5 mA]

RDS(ON)HS and RDS(ON)LS = on-resistance of step-down high and low side MOSFETS

3. The power dissipation for the linear charging mode can be calculated by the following equation:

$$P_{D(MAX)} = (V_{PIN} - V_{BAT}) \times I_{CH_BC} + V_{PIN} \times I_{QOP}$$

Where:

$P_{D(MAX)}$ = total power dissipation by the device

V_{PIN} = input voltage

V_{BAT} = battery voltage as seen at the BAT pin

I_{CH_BC} = battery conditioning charging current programmed for the application

I_{QOP} = quiescent current consumed by the charger IC for normal operation [5 mA].

By substitution, the maximum charging current before reaching the thermal limit condition (thermal loop) can be derived. The maximum charging current is the key factor when designing battery charger applications:

$$I_{CH_BC(MAX)} = \frac{P_{D(MAX)} - V_{PIN} \times I_{QOP}}{V_{PIN} - V_{BAT}}$$

$$I_{CH(MAX)} = \frac{\frac{T_J - T_A}{\theta_{JA}} - V_{PIN} \times I_{QOP}}{V_{IN} - V_{BAT}}$$

In general, the worst condition is the greatest voltage drop across the charger IC, when battery voltage is charged up to the preconditioning voltage threshold and entering Constant-Current (CC) switching charging mode.

Example Worst-Case Power Dissipation

The worst-case power dissipation can be calculated using the lowest battery voltage level when the charger enters CC charging mode and the charging current is set to 2 A:

$I_{CH_CC} = 2 \text{ A}$

$V_{PIN} = 6 \text{ V}$

$R_{DS(ON)HS} = 0.3 \ \Omega$

$R_{DS(ON)LS} = 0.25 \ \Omega$

$t_{SW} = 5 \times 10^{-9}$

$I_{QOP} = 0.005 \text{ A}$

$f_{SW} = 1.5 \times 10^6$

$T_A = 85 \text{ }^\circ\text{C}$

$\theta_{JA} = 50 \text{ }^\circ\text{C/W}$

$$P_{D(MAX)} = \frac{(2\text{A})^2 \times [0.3\ \Omega \times 2.8\text{V} + 0.25\ \Omega \times (6\text{V} - 2.8\text{V})]}{6\text{V}}$$

$$+ [(5 \times 10^{-9}) \times (1.5 \times 10^6) \times 2\text{A} + 0.005\text{A}] \times 6\text{V}$$

$$P_{D(MAX)} = 1.213\text{W}$$

$$T_{J(MAX)} = 85 + 50 \times 1.213(^\circ\text{C})$$

$$T_{J(MAX)} = 145.65(^\circ\text{C})$$

For the linear mode:

$I_{QOP} = 0.005 \text{ A}$

$V_{PIN} = 6 \text{ V}$

$V_{BAT} = 2 \text{ V}$

$I_{CH_BC} = 0.2 \text{ A}$

$$P_{D(MAX)} = (6\text{V} - 2\text{V}) \times 0.2\text{A} + 6\text{V} \times 0.005\text{A}$$

$$P_{D(MAX)} = 0.83\text{W}$$

PCB Layout Guidance

When laying out the PC board, follow the guidelines below to ensure proper operation of the AAT3620:

- Solder the exposed pad EP reliably to PGND/AGND and multilayer GND. Connect the exposed thermal pad to board ground plane and pins 2 and 3. Include a large exposed copper pad under the package in the ground plane with vias to all board layers for thermal dissipation.
- Keep the power traces, including GND traces, the LX traces and the VIN trace short, direct and wide to allow large current flow. Make the L1 connection to the LX and CS pins as short as possible. Use several via pads when routing between layers.
- Connect the input capacitors (C1, C4, and C5) as close as possible to VPIN (pin 1), VCC (pin 4) and GND/PGND (pins 2, 3) to get good power filtering. It is recommended to add a resistor R7 between VIN and VCC to create a low-pass RC filter on VCC.
- Connect the output capacitors C2, C6 and C7 and inductor L1 as close as possible, and do not route any signal lines under the inductor.
- Keep the resistance of the trace from the load return to the PGND (pin 2) to a minimum. This helps to minimize any error in DC regulation due to differences in the potential of the internal signal ground and the power ground.

Evaluation Board Description

The AAT3620 Evaluation Board is used to test the performance of the AAT3620. An Evaluation Board schematic diagram is provided in Figure 15. Layer details for the Evaluation Board are shown in Figure 16. The Evaluation Board has additional components for easy evaluation; the actual bill of materials required for the system is shown in Table 8.

Package Information

Package dimensions for the 14-pin TDFN33 package are shown in Figure 17. Tape and reel dimensions are shown in Figure 18.

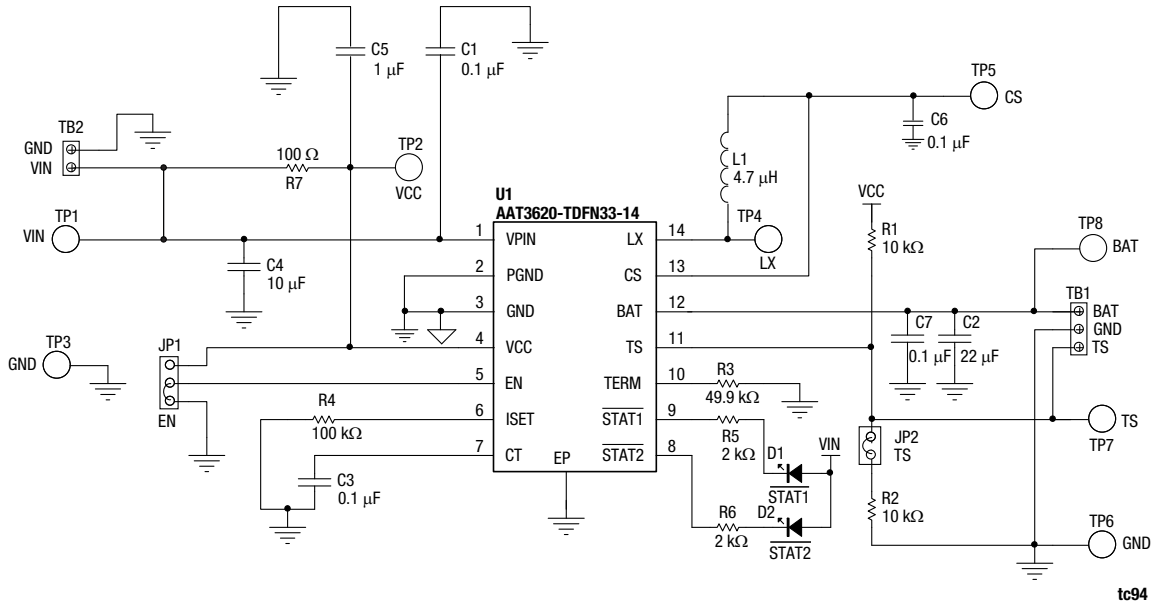
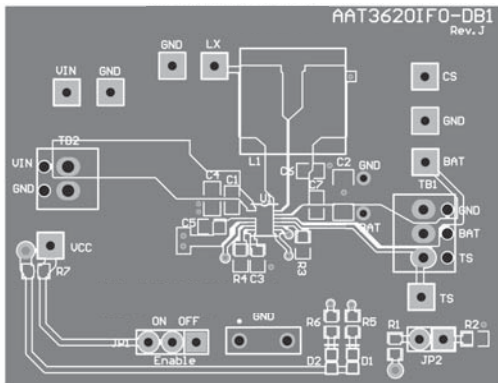


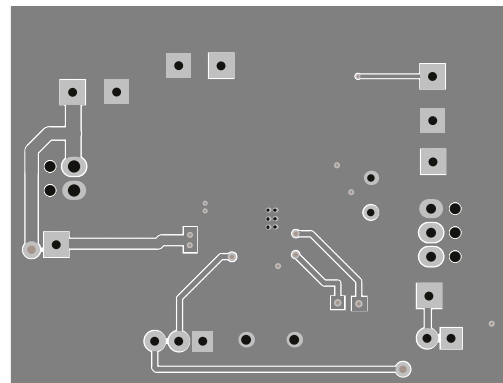
Figure 15. AAT3620 Evaluation Board Schematic

Table 8. AAT3620 Evaluation Board Bill of Materials

| Component | Description | Value | Footprint |
|----------------|-------------------------------------|---------|-------------|
| C4 | Capacitor, Ceramic, X5R, 10 V, ±20% | 10 μF | 0805 |
| C1, C3, C6, C7 | Capacitor, Ceramic, 20%, 10 V, X5R | 0.1 μF | 0603 |
| C2 | Capacitor, Ceramic, 20%, 10 V, X5R | 22 μF | 1206 |
| C5 | Capacitor, Ceramic, 20%, 10 V, X5R | 1 μF | 0603 |
| L1 | Inductor, Würth, 7447789004 | 4.7 μH | 7 mm × 7 mm |
| R1, R2 | Resistor, 5% | 10 kΩ | 0402 |
| R5, R6 | Resistor, 5% | 2 kΩ | 0402 |
| R3 | Resistor, 1% | 49.9 kΩ | 0402 |
| R4 | Resistor, 1% | 100 kΩ | 0402 |
| R7 | Resistor, 1% | 100 Ω | 0402 |
| D1, D2 | Red and green SMD | | 0402 |



(a) Top Layer



(b) Bottom Layer

Figure 16. AAT3620 Evaluation Board Layer Details

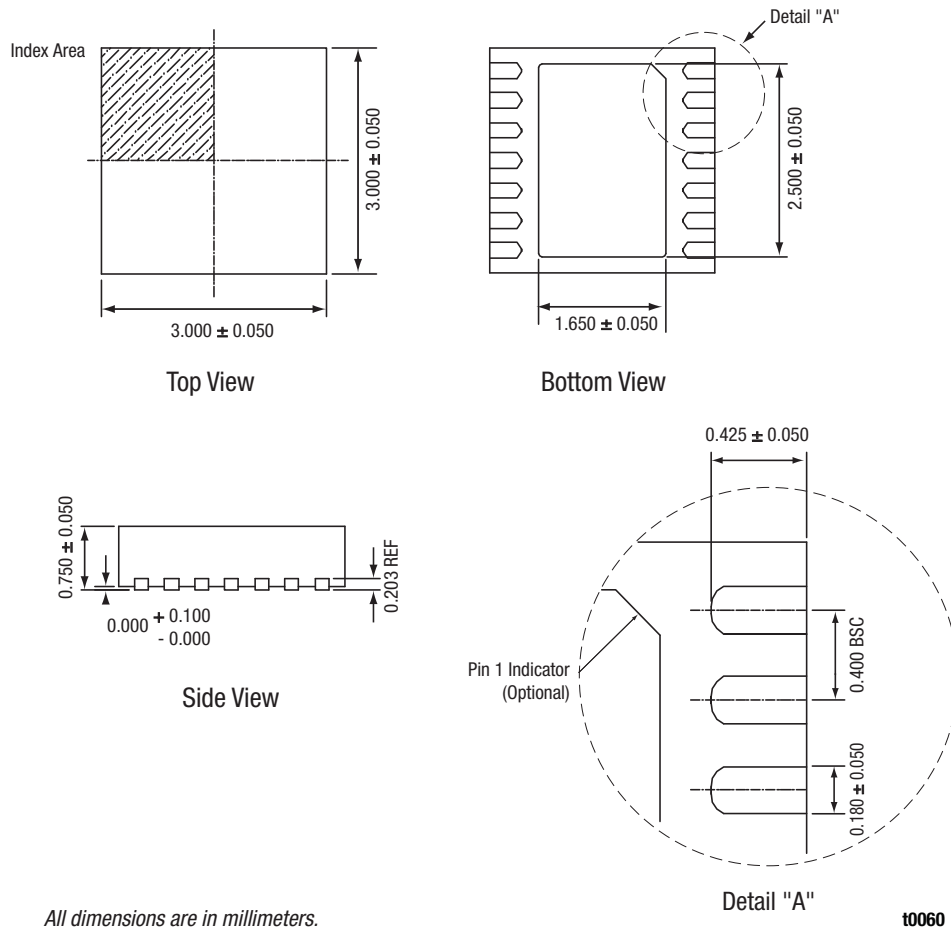


Figure 17. AAT3620 14-pin TDFN Package Dimensions

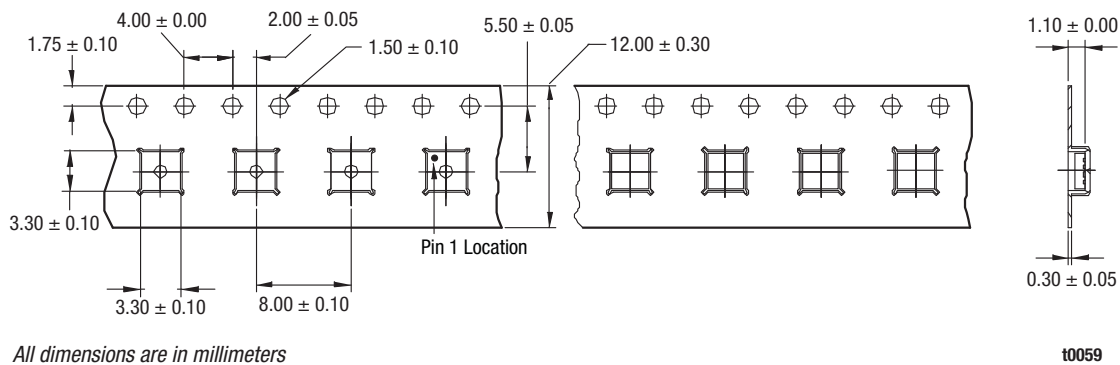


Figure 18. AAT3620 Tape and Reel Dimensions

Ordering Information

| Model Name | Part Marking (Note 2) | Manufacturing Part Number (Note 1) | Evaluation Board Part Number |
|---|-----------------------|------------------------------------|------------------------------|
| AAT3620 Single Cell Li+ Switch Mode Battery Charger | 6WXY | AAT3620IWO-4.2-T1 | AAT3620IWO-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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