# AAT1403

## *Serial LED Driver with Filtered PWM and 32-Step S²C Dimming Control*

## General Description

The AAT1403 is a step-up single channel LED driver with an input voltage range of 2.7V to 5.5V. The wide input voltage range, small solution size, advanced dimming features and high efficiency is suitable for LED backlight solutions for single cell Li-ion based equipment. A precision, high voltage current sink maintains the maximum LED current set by an external resistor from 10 to 31mA. The high switching frequency supports ultra small, low cost filtering components.

Two dimming controls are available; 32 dimming steps using the S²Cwire™ interface, and filtered PWM control. The frequency range of the PWM dimming extends up to 100 kHz eliminating audible noise and suitable for CABC (Content Adaptive Brightness Control) applications.

The device includes over-temperature protection and programmable over-voltage protection and recovers automatically when the fault is removed. The AAT1403 is available in a 10-pin wafer-level chip scale package (WLCSP) and is rated over the -40°C to +85°C temperature range.

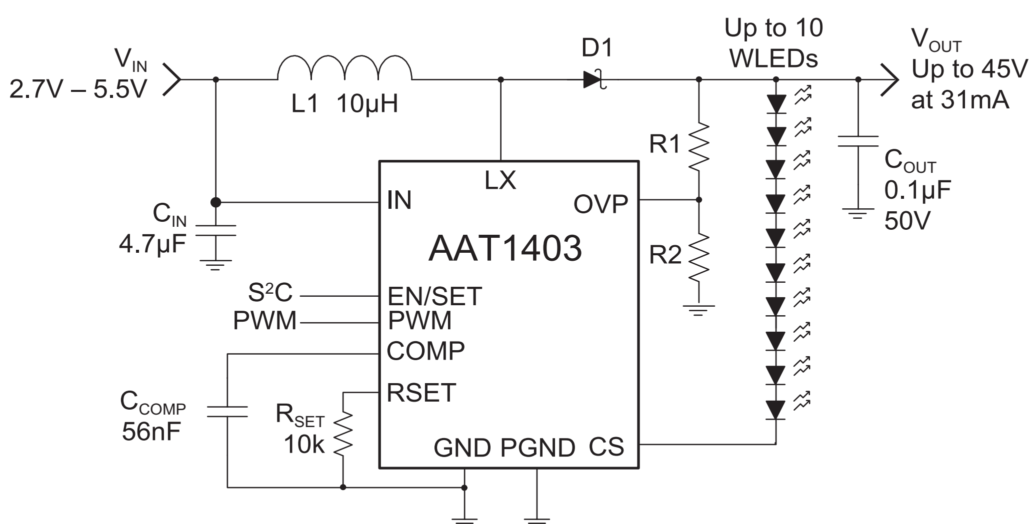
## Features

- Input Voltage Range: 2.7 to 5.5V
- Drives Up to 45V with Typical 10 Series LEDs at 31mA
- 1MHz Switching Frequency Allows Small External Components
- Up to 81% Efficiency with 10µH Inductor
- Dimming Control Options:
  - 32 Steps - S²Cwire Single Wire Interface
  - Filtered PWM
- Low Operating Current at 2.3mA
- Shutdown Current < 1µA
- Over-Voltage Protection for Open-LED Faults
- Over-Temperature Protection
- Ultra Small, Low Profile 10-pin 1.55 x 1.15mm WLCSP Package

## Applications

- Digital Still Cameras (DSC)
- Mobile Handsets
- Netbooks and Notebooks
- Portable Media Players
- White LED Drivers

## Typical Application

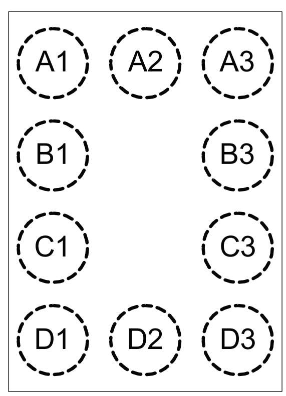


## Pin Descriptions

| Pin # | Symbol | Function |
|---|---|---|
| A1 | LX | Switching node of boost converter. Connect an inductor between LX and input supply (VIN); Schottky rectifier anode is connected between LX pin while cathode is connected to output capacitor. |
| A2 | IN | Supply input for the IC. Connect a 4.7μF 6.3V/10V ceramic capacitor from this pin to GND. |
| A3 | EN/SET | Enable on/off control and S²Cwire interface input. |
| B1 | PGND | Power ground pin. |
| B3 | PWM | Input PWM pin. Pull high to disable the PWM dimming feature. |
| C1 | GND | Ground pin. |
| C3 | COMP | Compensation pin. Connect a capacitor from this pin to GND. Compensation components are mainly related to the output capacitor valued. See the Capacitor Selection section in the Application Information section of this datasheet. |
| D1 | CS | Connect to the cathode of the last diode of the LED string. |
| D2 | RSET | Connect a resistor to GND to set maximum LED current up to 31mA. |
| D3 | OVP | Feedback pin for over-voltage protection. |

## Pin Configuration

**WLCSP10 1.1 x1.5**
**(Top View)**



*Serial LED Driver with Filtered PWM and 32-Step S²C Dimming Control*

## Absolute Maximum Ratings[1]

| Symbol | Description | Value | Units |
|---|---|---|---|
| $V_{IN}$ | IN to GND, PGND | -0.3 to 6.0 | V |
| $V_{LX}$ | LX to GND, PGND | -0.3 to 50 | V |
| $V_{CS}$ | SINK to GND, PGND | -0.3 to 35 | V |
| $V_{EN/SET}$, $V_{PWM}$, $V_{RSET}$, $V_{COMP}$, $V_{OVP}$ | EN/SET, PWM, RSET, COMP, OVP to GND/PGND | -0.3 to IN +0.3 | V |

## Thermal Information[2]

| Symbol | Description | Value | Units |
|---|---|---|---|
| $\Theta_{JA}$ | Thermal Resistance | 122 | °C/W |
| $P_D$ | Maximum Power Dissipation | 820 | mW |
| $T_J$ | Maximum Junction Operating Temperature | -40 to +155 | °C |
| $T_{LEAD}$ | Maximum Soldering Temperature (at leads, 10 sec.) | 300 | |

## Recommended Operating Conditions

| Symbol | Description | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| $V_{IN}$ | Input Supply Voltage | 2.7 | | 5.5 | V |
| $V_{OUT}$ | Boosted Output Voltage | $V_{IN}$ + 3V | | $V_{OUT}$[3] | V |
| L1 | Inductor Value | 4.7 | 10 | 22 | µH |
| $F_{PWM-F}$ | Input Filtered PWM Frequency | 100 | | 100,000 | Hz |
| $T_A$ | Ambient Temperature Range | - 40 | | 85 | °C |

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

## Electrical Characteristics[1]

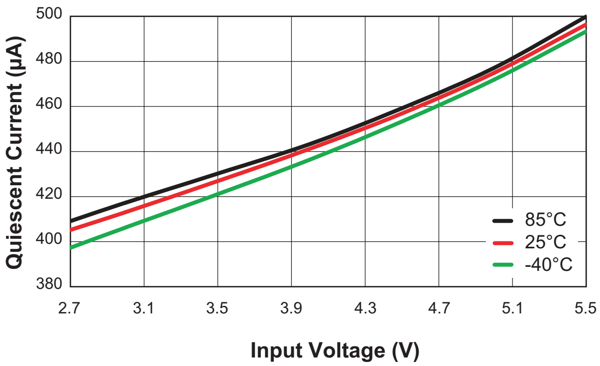
$V_{IN}$ = 3.6V, $C_{IN}$ = 4.7µF, $C_{OUT}$ = 0.1µF, L = 10µH, $R_{SET}$ = 10KΩ, $T_A$ = -40°C to 85°C unless otherwise noted. Typical values are at $T_A$= 25°C.

| Symbol | Description | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| $V_{IN}$ | Input Voltage Range | | 2.7 | | 5.5 | V |
| $V_{OUT}$ | Maximum Output Voltage | | | | 45 | V |
| $I_Q$ | Quiescent Supply Current | $V_{ENSET}$ = $V_{IN}$ | | 430 | 700 | µA |
| $I_{SHDN}$ | Input Shutdown Current | $V_{ENSET}$ = 0V | | | 1 | µA |
| $I_{QSW}$ | Input Switching Current | $V_{ENSET}$ = $V_{IN}$ | | 2.3 | | mA |
| $R_{DS(ON)N}$ | NMOS On-Resistance | $T_A$ = 25°C | | 650 | | mΩ |
| η | Maximum Efficiency | $I_{OUT}$ = 31mA | | 81 | | % |
| $F_{osc}$ | Switching Frequency | $T_A$ = 25°C | | 1.0 | | MHz |
| $T_{SS}$ | Soft-Start Time | $V_{ENSET}$ = $V_{IN}$ to 95% of output regulation, $C_{COMP}$ = 56nF | | 5 | | ms |
| $D_{MAX}$ | Maximum Duty Cycle | | 94.0 | | | % |
| $V_{OVP-T}$ | OUT Over-Voltage Protection Threshold | $V_{OVP}$ rising | 1.1 | 1.2 | 1.3 | V |
| $V_{OVPH}$ | Over-Voltage Protection Hysteresis | | | 75 | | mV |
| $T_{SD}$ | Over-Temperature Shutdown Threshold | | | 155 | | °C |
| $T_{HYS}$ | Over-Temperature Shutdown Hysteresis | | | 15 | | °C |
| $V_{CS}$ | Current Sink Voltage | $I_{OUT}$ = 31mA | | 500 | | mV |
| $I_{CS(ACC)}$ | Current Sink Accuracy | $R_{SET}$ = 10KΩ | 27.9 | 31.0 | 34.1 | mA |
| $V_{RSET}$ | RSET Voltage | $R_{SET}$ = 10KΩ | | 1.206 | | V |
| **EN/SET** | | | | | | |
| $V_{EN/SET (L)}$ | EN/SET | $V_{IN}$ = 2.7V to 5.5V | | | 0.4 | V |
| $V_{EN/SET (H)}$ | EN/SET | $V_{IN}$ = 2.7V to 5.5V | 1.4 | | | V |
| $t_{EN/SET(LOW)}$ | EN/SET Input Low Time | | 0.3 | | 75 | µs |
| $t_{EN/SET(HI\_MIN)}$ | EN/SET Minimum High Time | | 100 | | | ns |
| $t_{EN/SET(HIMAX)}$ | EN/SET Maximum High Time | | | | 75 | µs |
| $t_{EN/SET(OFF)}$ | EN/SET Input Off Timeout | | | | 500 | µs |
| $t_{EN/SET(LAT)}$ | EN/SET Latch Timeout | | | | 500 | µs |
| $I_{EN/SET (LK)}$ | EN Input Leakage | $V_{ENSET}$ = 5V, $V_{IN}$ = 5V | -1 | | 1 | µA |
| **PWM** | | | | | | |
| $V_{PWM(L)}$ | Logic Threshold Low | | | | 0.4 | V |
| $V_{PWM(H)}$ | Logic Threshold High | | 1.4 | | | V |
| $I_{PWM(LK)}$ | PWM Input Leakage | $V_{PWM}$ = 5V, $V_{IN}$ = 5V | -1 | | 1 | µA |

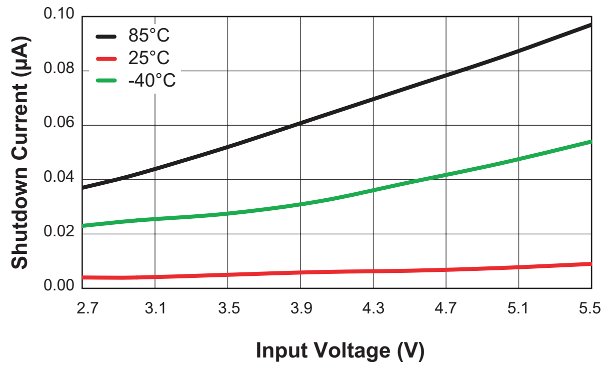
1. The AAT1403 is guaranteed to meet performance specification over the –40°C to +85°C operating temperature range, and is assured by design, characterization and correlation with statistical process controls.

## Typical Characteristics

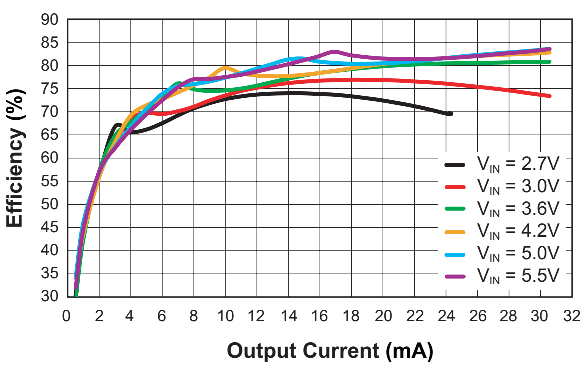
**Quiescent Current vs. Input Voltage**



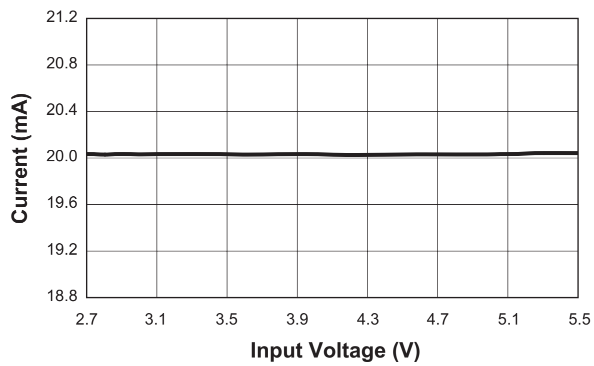

**Shutdown Current vs. Input Voltage**



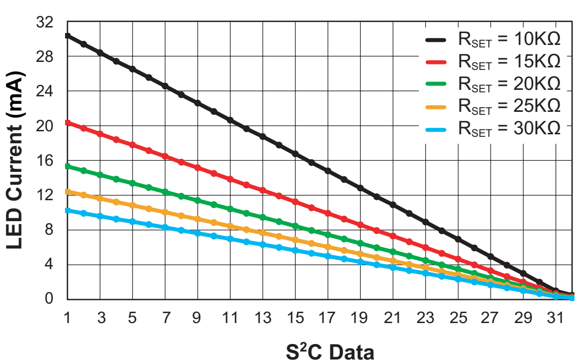

**Efficiency vs. Output Current**
**($R_{SET}$ = 10KΩ, L = 10μH, 10 LEDs)**



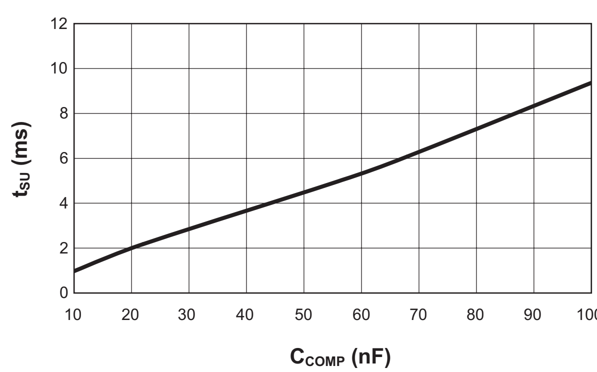

**LED Current Accuracy vs. Input Voltage**
**($V_{IN}$ = 3.6V, $R_{SET}$ = 15KΩ)**




**LED Current Accuracy vs. S²C**
**($V_{IN}$ = 3.6V, L = 10μH)**

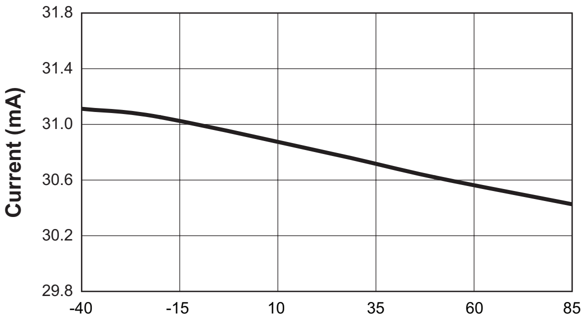



**Startup Time vs. $C_{COMP}$**
**(10 WLEDs)**

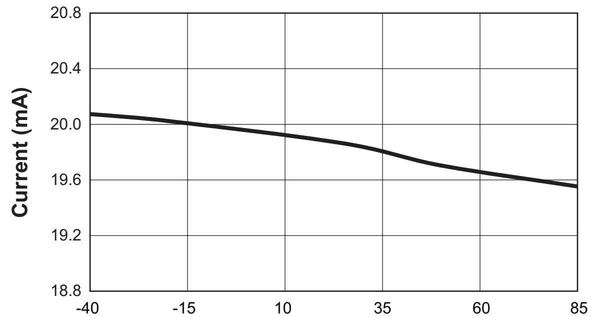


## Typical Characteristics

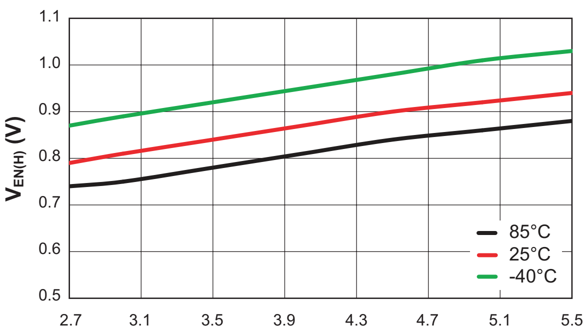
**LED Current Accuracy vs. Temperature**
**($V_{IN}$ = 3.6V, $R_{SET}$ = 10kΩ)**



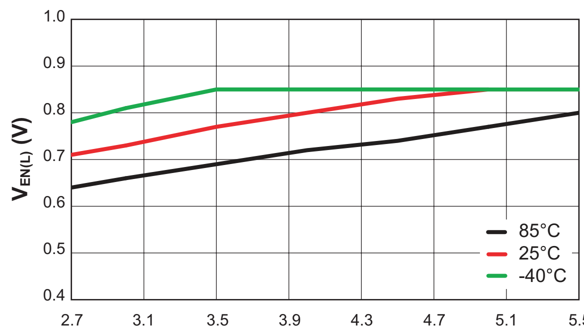

**LED Current Accuracy vs. Temperature**
**($V_{IN}$ = 3.6V, $R_{SET}$ = 15kΩ)**



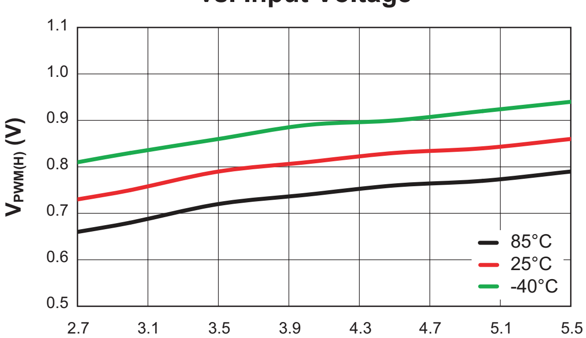

**EN Input High Threshold Voltage vs. Input Voltage**



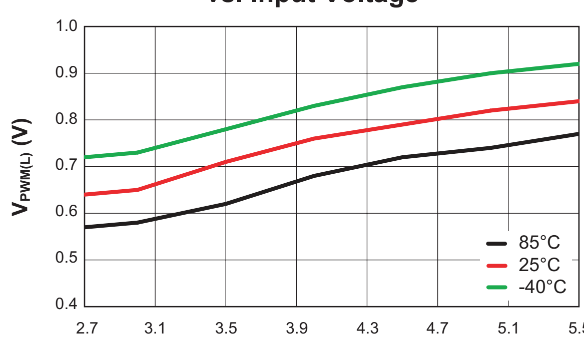

**EN Input Low Threshold Voltage vs. Input Voltage**




**PWM Input High Threshold Voltage vs. Input Voltage**

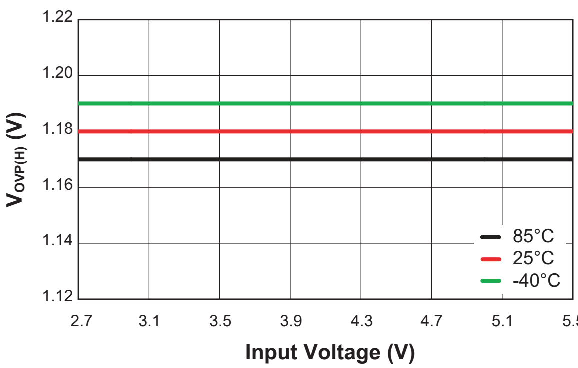



**PWM Input Low Threshold Voltage vs. Input Voltage**

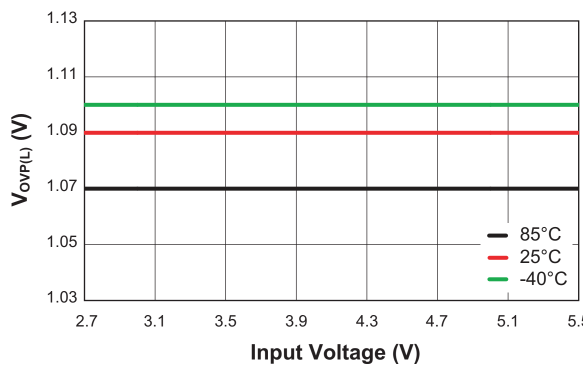


## Typical Characteristics

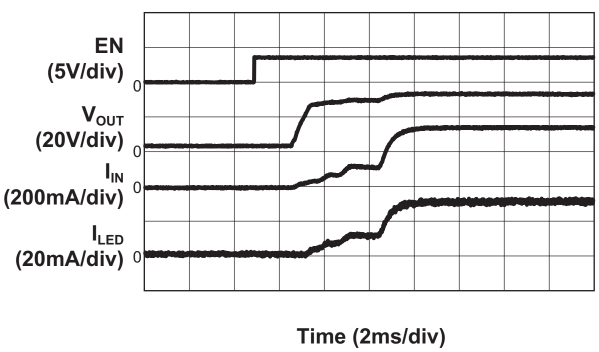
**OVP High Threshold Voltage vs. Input Voltage**



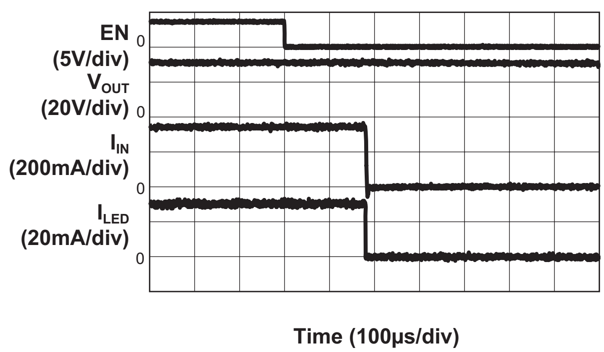

**OVP Low Threshold Voltage vs. Input Voltage**



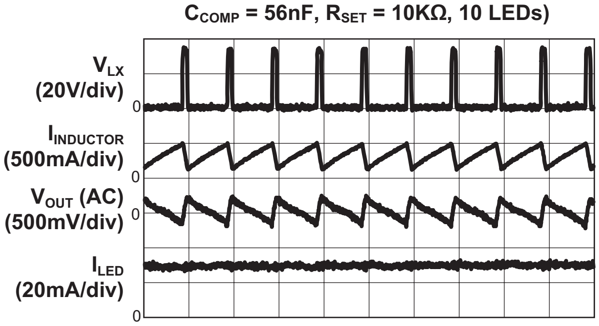

**Startup Waveform**
**($V_{IN}$ = 3.6V; $C_{IN}$ = 4.7µF, $C_{OUT}$ = 0.1µF, $C_{COMP}$ = 56nF, $R_{SET}$ = 10KΩ, 10 LEDs)**



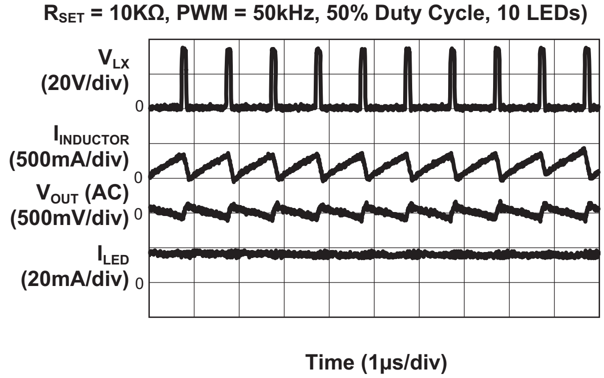

**Turn Off**
**($V_{IN}$ = 3.6V; $C_{IN}$ = 4.7µF, $C_{OUT}$ = 0.1µF, $C_{COMP}$ = 56nF, $R_{SET}$ = 10KΩ, 10 LEDs)**




**Operation Waveform**
**($V_{IN}$ = PWM = 3.6V; $C_{IN}$ = 4.7µF, $C_{OUT}$ = 0.1µF, $C_{COMP}$ = 56nF, $R_{SET}$ = 10KΩ, 10 LEDs)**

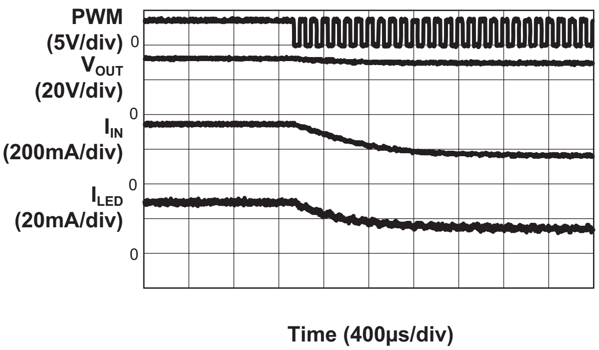



**Operation Waveform**
**($V_{IN}$ = 3.6V; $C_{IN}$ = 4.7µF, $C_{OUT}$ = 0.1µF,$C_{COMP}$ = 56nF, $R_{SET}$ = 10KΩ, PWM = 50kHz, 50% Duty Cycle, 10 LEDs)**

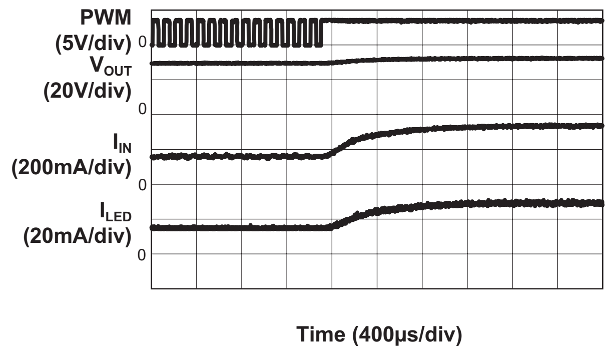


## Typical Characteristics

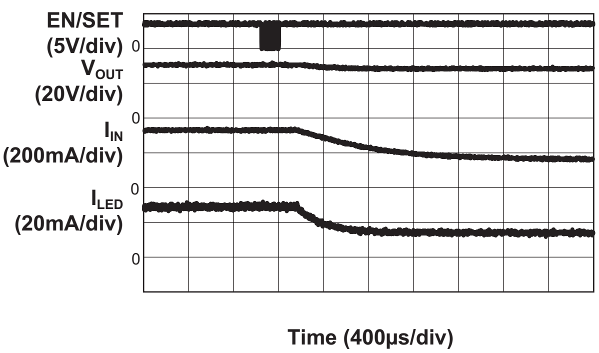
**LED Current Transition by PWM**
**($V_{IN}$ = 3.6V; $C_{IN}$ = 4.7µF, $C_{OUT}$ = 0.1µF, $C_{COMP}$ = 56nF, $R_{SET}$ = 10KΩ, PWM = 10KHz, 31mA to 15mA, 10 LEDs)**



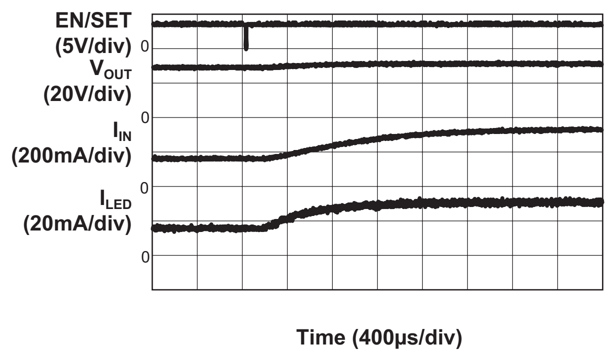

**LED Current Transition by PWM**
**($V_{IN}$ = 3.6V; $C_{IN}$ = 4.7µF, $C_{OUT}$ = 0.1µF, $C_{COMP}$ = 56nF, $R_{SET}$ = 10kΩ, PWM = 10KHz, 15mA to 31mA, 10 LEDs)**




**LED Current Transition by S²C**
**($V_{IN}$ = 3.6V; $C_{IN}$ = 4.7µF, $C_{OUT}$ = 0.1µF, $C_{COMP}$ = 56nF, $R_{SET}$ = 10KΩ, S²C Data 1 to 16, 10 LEDs)**




**LED Current Transition by S²C**
**($V_{IN}$ = 3.6V; $C_{IN}$ = 4.7µF, $C_{OUT}$ = 0.1µF, $C_{COMP}$ = 56nF, $R_{SET}$ = 10KΩ, S²C Data 16 to 1, 10 LEDs)**





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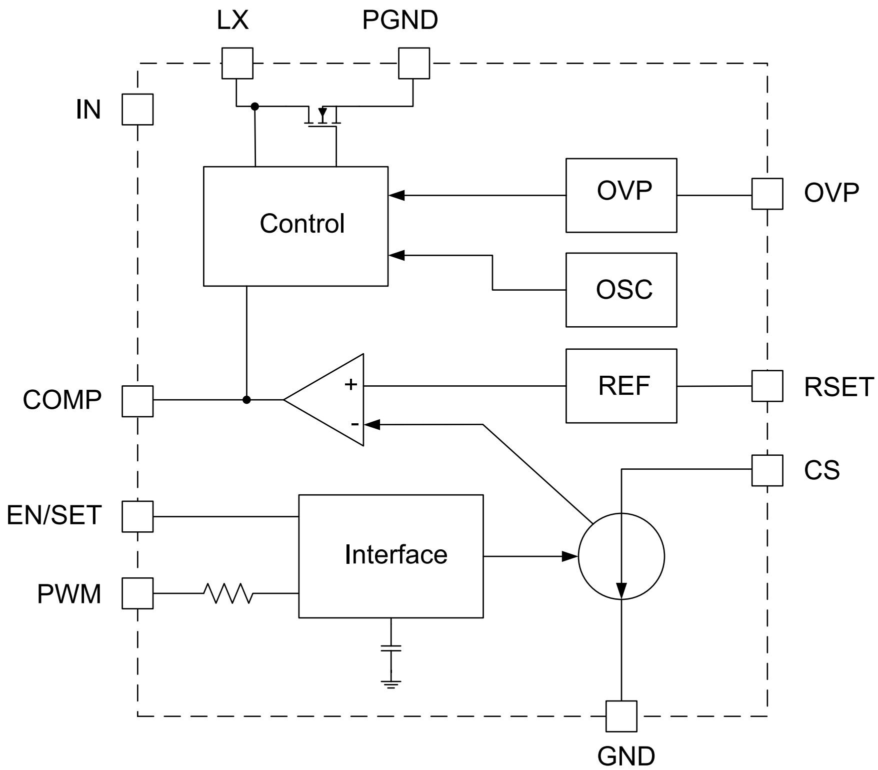
*Serial LED Driver with Filtered PWM and 32-Step S²C Dimming Control*

## Functional Block Diagram




## Functional Description

The AAT1403 is a high frequency current mode controlled step-up (boost) converter LED driver. The device utilizes a single current sink to regulate the LED current by controlling the output voltage. The wide voltage range is suitable for single cell Li-ion / Li-polymer battery applications. The internal current sink is programmed by an external resistor to a current from 10mA to 31mA. The minimum output voltage must be greater than the input voltage. The AAT1403 is capable of driving up to 45V with 10 series connected LEDs with currents up to 31mA. The LED dimming method is through either the S²Cwire interface with 32 steps or varied duty cycle of the PWM signal with frequency up to 100kHz after the maximum LED current is set by S²Cwire.

The over-voltage protection function is designed to protect the boost converter during the fault of the open circuit of the LED string. The over-temperature function is targeted to protect the converter if an over-temperature fault occurs. The AAT1403 will recover to normal operation automatically when the OVP or OTP fault is removed.

### Soft Start / Enable

The AAT1403 is enabled by EN/SET pulled to high after power on with a certain delay time. Internal soft start circuitry limits the input inrush current and eliminates output voltage overshoot. When ENSET is pulled low the AAT1403 enters a low-power, non-switching state. The total input current during shutdown is less than 1μA. An external diode limits $V_{OUT}$ to the level of $V_{IN}$ during shutdown. The diode consumes a small amount of additional input current depending on the OVP resistor divider value.

### Over-Temperature Protection

Thermal protection disables the AAT1403 when internal dissipation becomes excessive. Thermal protection disables the power MOSFET. The junction over-temperature threshold is 155°C with 15°C of temperature hysteresis. The output voltage automatically recovers when the over-temperature fault condition is removed.

## Over-Voltage Protection

Over-voltage protection prevents damage to the AAT1403's LX pin during open-circuit or high output voltage conditions. An over-voltage event is defined as a condition where the voltage on the OVP pin exceeds the over-voltage protection threshold ($V_{OVP-T}$). When $V_{OVP}$ has reached the threshold limit, the converter stops switching and the output voltage decays. Switching resumes when the lower hysteresis limit of $V_{OVP}$ is reached, thereby maintaining an average output voltage between the upper and lower OVP thresholds.

## LED Current Setting

The maximum LED current is determined by the $R_{SET}$ resistor value. With a fixed 1.2V voltage on $R_{SET}$, the LED maximum current is a linear ratio to the current flowing through $R_{SET}$.

$$I_{LED} = \frac{V_{SET}}{R_{SET}} \cdot 258$$

The LED dimming is controlled via one of two options, either using the 32-step S²Cwire single-wire interface via the EN/SET pin or PWM control with varied duty cycle up to 100kHz frequency. 32 S²Cwire rising-edge steps set the LED current from 100% to 2% percentage of the maximum LED current value when PWM control is disabled by pulling the PWM pin high. S²Cwire can also be used to set maximum LED current along with a PWM signal to dim the LED lighting from 100% to 1% of duty cycle.

## S²Cwire™ Serial Interface

The LED current magnitude can be controlled by the EN/SET pin using the S²Cwire interface. The interface records rising edges of the EN/SET pin and decodes them into 32 individual current level settings. Code 1 is full scale (maximum LED current), and Code 32 is 2% of the full scale. The modulo 32 interface wraps states back to state 1 after the 32nd clock. The counter can be clocked at speeds up to 1MHz, so intermediate states are not visible. The first rising edge of EN/SET enables the IC and initially sets the output LED current to full scale after 500μs $t_{LAT}$. Once the final clock cycle is input for the desired brightness level, the EN/SET pin should be held high to maintain the device output current at the programmed level. The device is disabled 500μs after the EN/SET pin enters a logic low state. The EN/SET timing is designed to accommodate a wide range of data rates from 20kHz to 1MHz.

After the first rising edge of EN/SET, the boost converter is enabled and reaches full capacity after the soft-start time. Exact counts of clock pulses for the desired current level should be entered on the EN/SET pin with a single burst of clocks. The counter refreshes each time a new clock input to the EN/SET pin is detected. A constant current is maintained as long as EN/SET remains in a logic high state. To save power, the boost converter is switched off after EN/SET has remained in the low state for at least the $t_{OFF}$ timeout period as shown in Figure 1.

## S²Cwire Serial Interface Timing

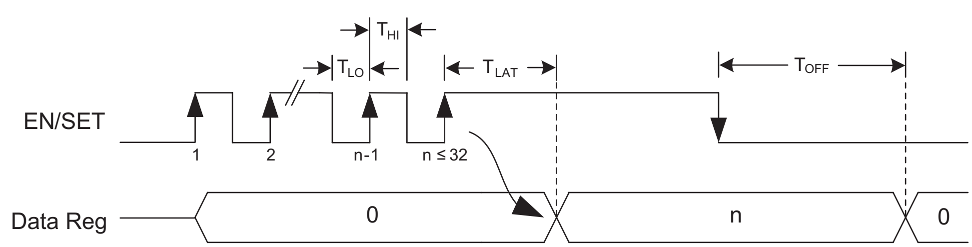



**Figure 1: S²Cwire Timing Diagram.**

# Application Information

## LED Current Setting

The maximum LED current is determined by value of the external resistor $R_{SET}$ from 10mA to 31mA. The value of $R_{SET}$ is determined by the voltage of $R_{SET}$ and the LED current, and can be calculated by:

$$R_{SET} = \frac{V_{SET} \cdot 258}{I_{LED}}$$

Where $V_{SET}$ = 1.2V. Table 1 lists examples of standard 1% metal film $R_{SET}$ values for different maximum LED current requirements.

| Maximum LED Current (mA) | $R_{SET}$ (kΩ) |
|---|---|
| 31 | 10 |
| 20 | 15 |
| 15 | 20 |
| 12 | 25 |
| 10 | 30 |

**Table 1: Examples of Standard 1% $R_{SET}$ Values for Setting Maximum LED Current Levels.**

LED current dimming is controlled either via the S²Cwire single-wire interface through the EN/SET pin in 32 steps or via PWM control with varied duty cycle up to 100kHz frequency. The S²Cwire interface programs the LED current from the maximum LED current set by $R_{SET}$ to 2% of the maximum LED current as shown in Table 2.

| S²Cwire Data | LED Current (% $I_{MAX}$) | S²Cwire Data | LED Current (% $I_{MAX}$) |
|---|---|---|---|
| 1 | 100 | 17 | 48 |
| 2 | 97 | 18 | 45 |
| 3 | 94 | 19 | 42 |
| 4 | 90 | 20 | 39 |
| 5 | 87 | 21 | 35 |
| 6 | 84 | 22 | 32 |
| 7 | 81 | 23 | 29 |
| 8 | 77 | 24 | 26 |
| 9 | 74 | 25 | 23 |
| 10 | 71 | 26 | 19 |
| 11 | 68 | 27 | 16 |
| 12 | 65 | 28 | 13 |
| 13 | 61 | 29 | 10 |
| 14 | 58 | 30 | 6 |
| 15 | 55 | 31 | 3 |
| 16 | 52 | 32 | 2 |

**Table 2: S²Cwire Dimming Control Current Settings.**

Figure 2 illustrates the LED current value at different S²Cwire code settings when $R_{SET}$ is 15kΩ with a maximum LED current of 20mA.

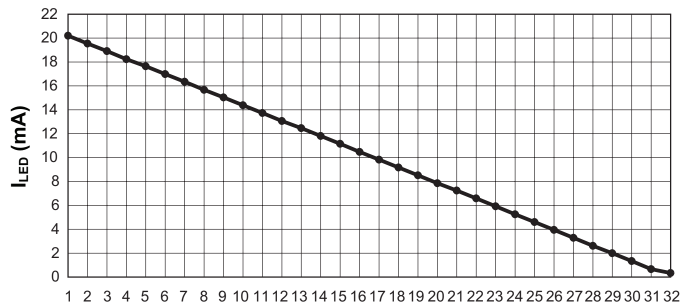



**Figure 2: S²Cwire Dimming Control at Maximum LED Current (20mA max).**

## Filtered PWM Dimming

The AAT1403 provides a PWM input as an additional means of providing dimming control for CABC applications. The LED current reduces percentage linearly as the duty cycle decreasing. Frequencies of up to 100kHz can be applied. To avoid output flicker and noise, the input control PWM frequency is filtered by the low pass filter composed of the error amplifier and the external compensation capacitor.

Figure 3 shows LED current dimming controlled by varying the PWM duty cycle at $R_{SET}$ = 15kΩ.

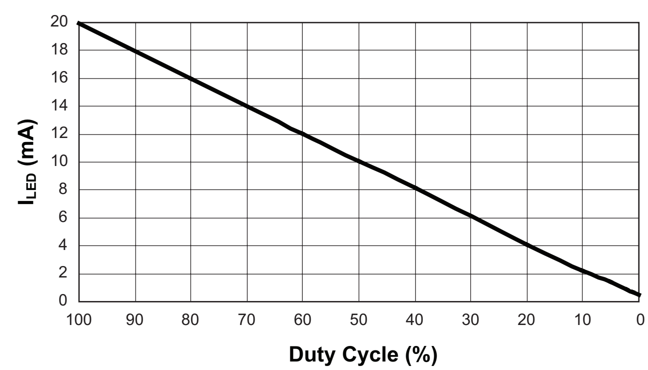



**Figure 3: Filtered PWM Dimming Duty Cycle vs. Maximum LED Current (20mA max).**

## Capacitor Selection

A compensation capacitor $C_{COM}$ is used for step-up converter loop compensation, soft startup time control, and PWM digital signal filtering. Loop compensation requires matching values for $C_{COM}$, $C_{OUT}$, $I_{LED}$, and $V_{OUT}$:

$$\frac{C_{OUT}}{C_{COM}} < \frac{I_{LED}}{30 \cdot 10^{-6} \cdot V_{OUT}}$$

The AAT1403 can drive up to 10 white LEDs with forward voltages up to 4V each. In a worst case with $V_F$ of 4V, a $C_{OUT}$ value of 0.1µF, and LED maximum current of 20mA, the value of $C_{COM}$ should be higher than 6.0nF.

$$C_{COM} > \frac{C_{OUT} \cdot 30 \cdot V_{OUT}}{I_{LED}} (nF) = \frac{0.1 \cdot 30 \cdot 40}{20} (nF) = 6.0nF$$

A higher value for $C_{COM}$ lengthens the soft startup time. The relationship between $C_{COM}$ and startup time is almost linear, with startup time x $10^5$ magnification of $C_{COM}$; thus 56nF $C_{COM}$ leads to a soft startup time of 5.6ms. Table 3 gives several examples of minimum $C_{COM}$ values at different $C_{OUT}$ and $I_{LED}$ and the step-up converter's operation stable. Values of 56nF for $C_{COM}$ and 0.1µF for $C_{OUT}$ are suitable in most cases.

| $I_{LED}$ (mA) | $C_{OUT}$ (µF) | $V_{OUT}$ (V) | $C_{COM\_MIN}$ (nF) |
|---|---|---|---|
| 31 | 0.1 | 40 | 3.9 |
| 31 | 1 | 40 | 39 |
| 20 | 0.1 | 40 | 6.0 |
| 20 | 1 | 40 | 60 |
| 10 | 0.1 | 40 | 12 |
| 10 | 1 | 40 | 120 |

**Table 3: Minimum $C_{COM}$ Values vs. $I_{LED}$ and $C_{OUT}$ (Step-Up Converter Operation Stable).**

Multi-layer ceramic (MLC) capacitors provide small size and adequate capacitance, low parasitic equivalent series resistance (ESR) and equivalent series inductance (ESL), and are well suited for use as input, output and compensation capacitors in the AAT1403 step-up converter LED driver application. MLC capacitors of type X7R or X5R are recommended to ensure good capacitance stability over the full operating temperature range. A 4.7µF/6.3V input capacitor is recommended and a 0.1µF/50V output capacitor is suitable as noted above. Table 4 lists some recommended capacitors for use with the AAT1403.

## Inductor Selection

Inductor value, saturation current and DCR is most important parameter in selecting an inductor for the AAT1403.

The suitable inductance range for the AAT1403 is 4.7µH to 22µH. Higher inductance lowers the step-up converter's RMS current value. Together with lower DCR value of the inductor, it makes the total inductor power loss become much lower. Considering inductor size and cost, 10µH inductance is most suitable. Figure 4 illustrates AAT1403 efficiency at different inductance with similar DCR value.

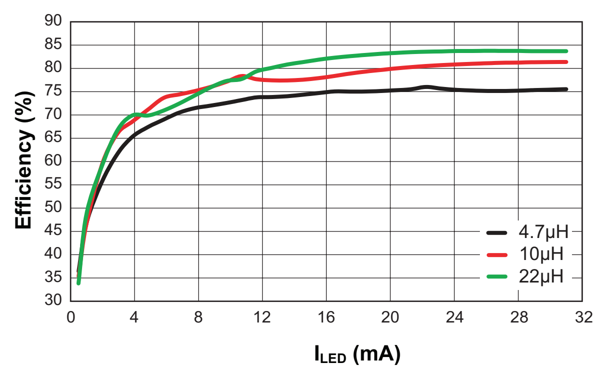



**Figure 4: AAT1403 Efficiency at Different Inductance with Similar DCR ($V_{IN}$ = 3.6V).**

| Manufacturer | Part Number | Value (µF) | Voltage (V) | Temperature Range | Case Size |
|---|---|---|---|---|---|
| Murata | GRM188R60J475K | 4.7 | 6.3 | X5R | 0603 |
| | GRM188R71H104KA93 | 0.1 | 50 | X7R | 0603 |

**Table 4: Examples of AAT1403 Input and Output Capacitor Selection.**

Considering the inductor copper loss, the inductor DCR value together with the RMS current value flowing through the inductor leads to inductor conduction loss and also affects total efficiency. Larger DCR leads to larger conduction loss and decreases total efficiency. The inductor conduction loss can be estimated as shown in the equation:

$$P_{L\_LOSS} = I^2_{L\_RMS} \cdot DCR$$

$$= \frac{1}{3} \cdot (I^2_{L\_MAX} + I^2_{L\_MIN} + I_{L\_MAX} \cdot I_{L\_MIN}) \cdot DCR$$

$I_{L\_MAX}$ and $I_{L\_MIN}$ are the inductor peak current and minimum current. Figure 5 shows DCR effects on efficiency with a 10µH inductor.

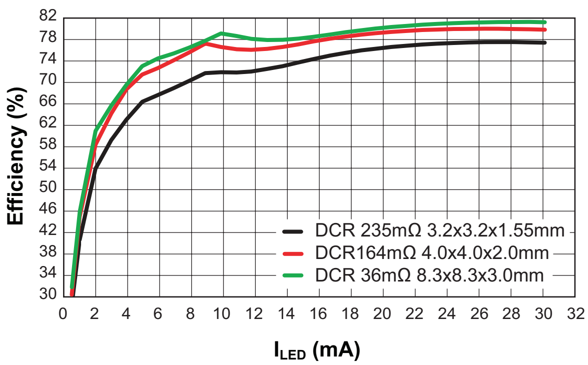



**Figure 5: Inductor DCR Effects on Total Efficiency with 10µH at 3.6V $V_{IN}$.**

Inductor saturation current is also a key parameter in selecting an inductor. For the step-up converter, the peak inductor current is the DC input current plus half the inductor peak-to-peak current ripple.

DC input current:

$$I_{IN} = \frac{V_{OUT} \cdot I_{LED}}{V_{IN} \cdot \eta}$$

Inductor peak-to-peak current ripple:

$$I_{L\_PP} = \frac{V_{IN} \cdot (V_{OUT} - V_{IN})}{V_{OUT} \cdot L \cdot f}$$

Inductor peak current:

$$I_{L\_PEAK} = I_{IN} + \frac{I_{L\_PP}}{2} = \frac{V_{OUT} \cdot I_{LED}}{V_{IN} \cdot \eta} + \frac{V_{IN} \cdot (V_{OUT} - V_{IN})}{2 \cdot V_{OUT} \cdot L \cdot f}$$

For example, for a white LED with 3.2V $V_F$ and 20mA current at 80% efficiency at 3.6V $V_{IN}$, the inductor peak current is

$$I_{L\_PEAK} = \frac{3.2 \cdot 10 \cdot 0.02}{3.6 \cdot 0.8} + \frac{3.6 \cdot (3.2 \cdot 10 - 3.6)}{2 \cdot 3.2 \cdot 10 \cdot 10\mu \cdot 1M} = 382mA$$

Table 5 gives some examples of recommended inductors for use with the AAT1403.

## OVP Setting

Over-voltage protection is designed to protect the step-up converter from a LED string open fault. The OVP threshold is 1.2V. For 6 white LEDs with $V_F$ up to 4V, the resistor divider values for R1 and R2 can be calculated by:

$$R_1 = \left(\frac{V_{OUT}}{V_{OVP\_TH}} - 1\right) \cdot R_2$$

Higher resistor divider values decrease the power loss on the resistors. The total resistor value for 40V $V_{OUT}$ should be less than 4MΩ for better noise immunity. Values of 2.2MΩ for resistor R1 and 68kΩ for resistor R2 are recommended.

| Manufacturer | Part Number | Inductance (µH) | Maximum DC $I_{SAT}$ Current (mA) | DCR (mΩ, typ) | Size (mm) LxWxH | Type |
|---|---|---|---|---|---|---|
| Sumida | CDRH3D18-100 | 10 | 900 | 164 | 4.0x4.0x2.0 | Shielded |
| | CDRH3D23-220 | 22 | 550 | 219 | 3.9x3.9x2.5 | Shielded |
| Murata | LQH44PN100MP0L | 10 | 1150 | 160 | 4.0x4.0x1.65 | Non-shielded |
| | LQH44PN220MP0L | 22 | 800 | 370 | 4.0x4.0x1.65 | Non-shielded |
| Coilcraft | EPL2014-103MLC | 10 | 600 | 440 | 2.1x2.2x1.0 | Shielded |
| | LPS4012-223MLC | 22 | 790 | 600 | 4.1x4.1x1.2 | Shielded |
| Coiltronics | SD18-100-R | 10 | 982 | 158 | 5.8x5.8x1.8 | Shielded |

**Table 5: Example of AAT1403 Inductor Selection.**

## Rectifier Diode Selection

An external rectifier diode is required for the non-synchronous step-up converter. A low $V_F$ Schottky diode is recommended. The diode voltage rating should be higher than the OVP voltage. For an AAT1403 driving 10 white LEDs with up to 4V forward voltage, the diode voltage rating should be higher than 40V. Select a diode with DC rated current equal to the input current to allow an adequate margin for safe use.

Table 6 gives some examples of recommended rectifier diodes for use with the AAT1403.

## Printed Circuit Board Layout Recommendations

For best performance of the AAT1403, the following guidelines should be followed when designing the PCB layout:

1. Make the power trace as short and wide as possible, including the input/output power lines and switching node, etc.
2. Make sure the ground bump connected to the printed circuit board with large copper area for better thermal dissipation.
3. Put the input and output capacitor close to the IC as close as possible to get the best filter result.

| Manufacturer | Part Number | Maximum DC Blocking Voltage $V_R$ (V) | Maximum DC Forward Current $I_F$ (mA) | Non-repetitive Peak Forward Surge Current $I_{FSM}$ (A) | Forward Voltage $V_F$ (V) | Case | Size WxLxH (mm) |
|---|---|---|---|---|---|---|---|
| Diodes | DFLS160 | 60 | 1000 | 5.0 | 0.5@1A | PowerDI 123 | 1.93x3.0x1.0 |
| TSC | SS15L | 50 | 1100 | 30 | 0.51@0.5A | Sub SMA | 1.9x3.8x1.43 |
| | SS16L | 60 | 1100 | 30 | 0.51@0.5A | Sub SMA | 1.9x3.8x1.43 |

**Table 6: Example of Typical Rectifier Diodes.**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## Schematic and Layout

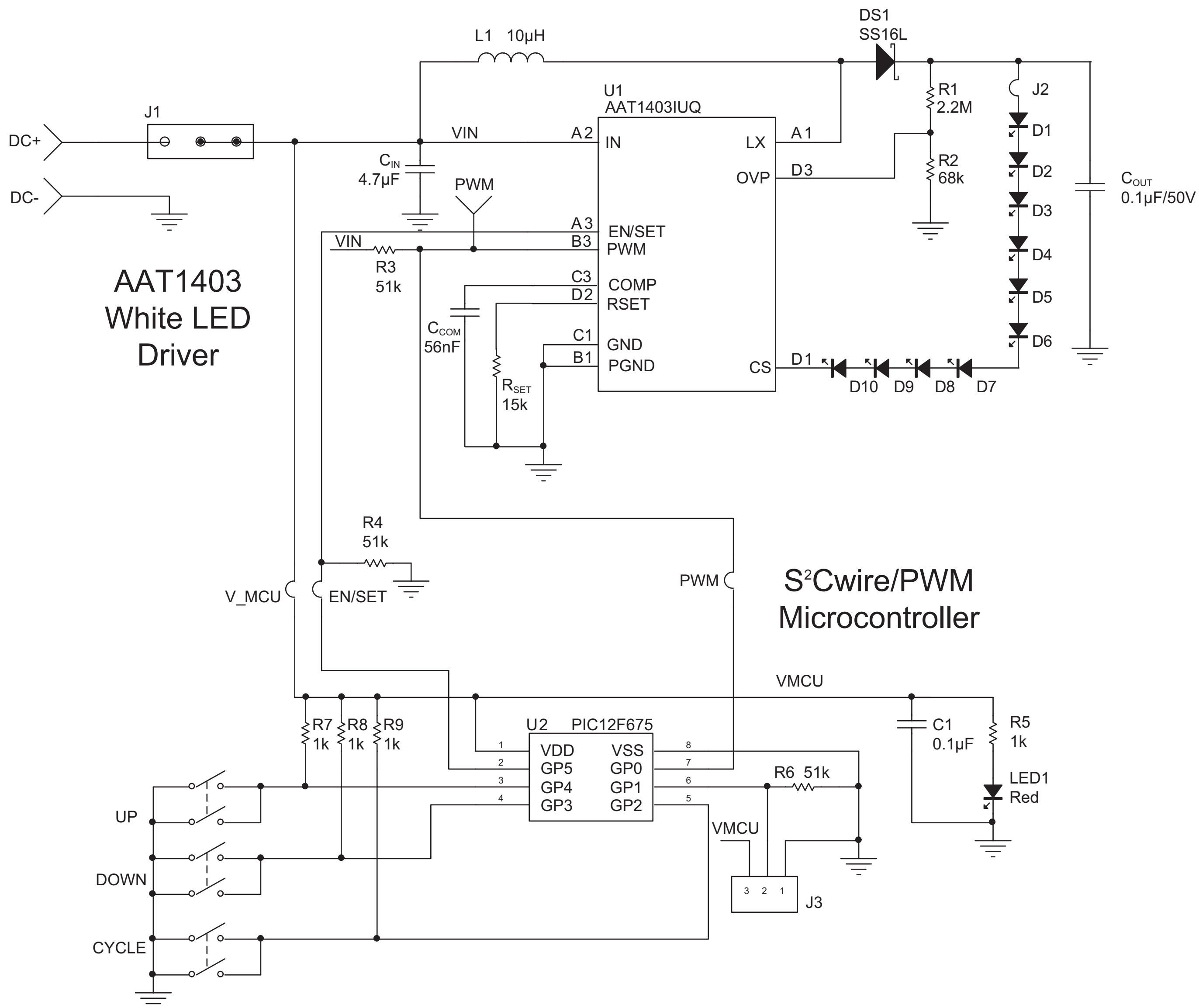



**Figure 6: AAT1403 Evaluation Board Schematic.**

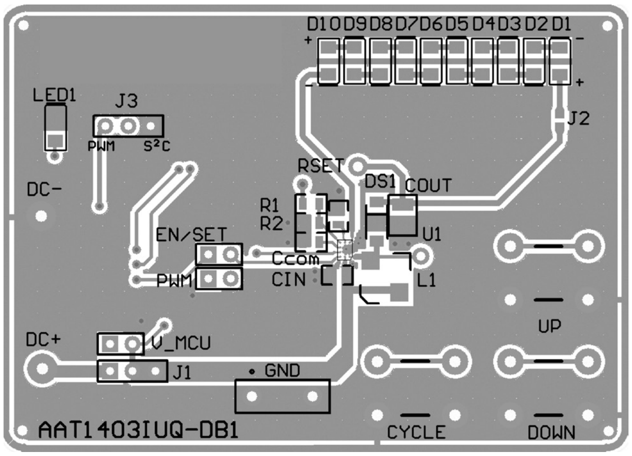



**Figure 7: AAT1403 Evaluation Board Top Side Layout.**

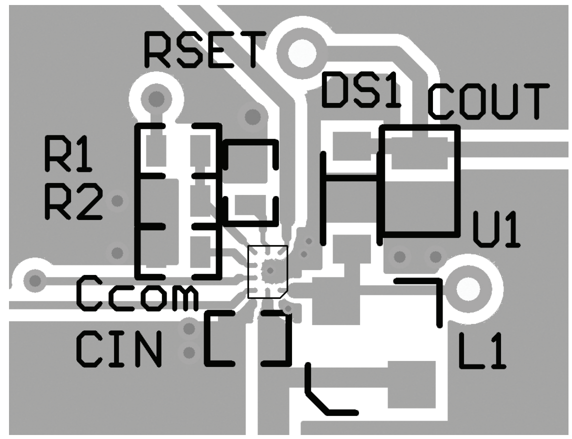



**Figure 8: AAT1403 Evaluation Board Top Side Layout (detail).**

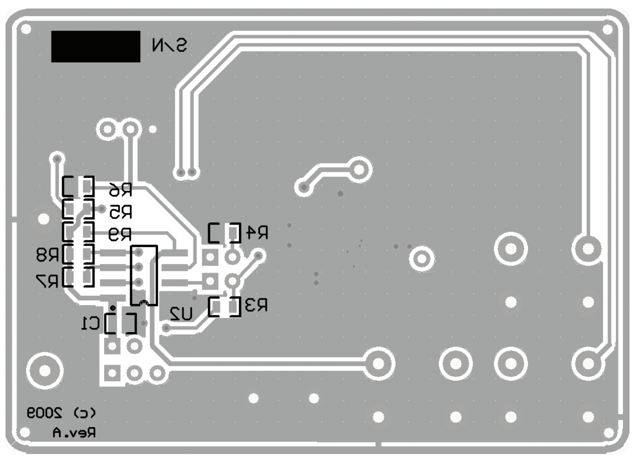


**Figure 9: AAT1403 Evaluation Board Bottom Side Layout.**

| Component | Part Number | Description | Manufacturer |
|---|---|---|---|
| U1 | AAT1403IUQ | High Efficiency Serial LED Driver for 6 White LEDs | Skyworks |
| U2 | PIC12F675 | 8-Pin Flash-Based 8-Bit CMOS Microcontroller | Microchip |
| R1 | RC0603FR-072M2L | Res 2.2MΩ 1/10W 1% 0603 SMD | Yageo |
| R2 | RC0603FR-0768KL | Res 68KΩ 1/10W 1% 0603 SMD | |
| R3, R4, R6 | RC0603FR-0751KL | Res 51KΩ 1/10W 1% 0603 SMD | |
| $R_{SET}$ | RC0603FR-0715KL | Res 15KΩ 1/10W 1% 0603 SMD | |
| R5, R7, R8, R9 | RC0603FR-071KL | Res 1KΩ 1/10W 1% 0603 SMD | |
| $C_{IN}$ | GRM188R60J475K | Cap Ceramic 4.7µF 0603 X5R 6.3V 10% | Murata |
| $C_{OUT}$ | GRM21BR71H104K | Cap Ceramic 0.1µF 0805 X7R 50V 10% | |
| C1 | GRM188R71C104K | Cap Ceramic 0.1µF 0603 X7R 16V 10% | |
| $C_{COM}$ | GRM188R71C563K | Cap Ceramic 0.056µF 0603 X7R 16V 10% | |
| D1, D2, D3, D4, D5, D6, D7, D8, D9, D10 | RS-0805UW | 20mA White LED 0805 | Realstar |
| DS1 | SS16L | Surface Mount Schottky Barrier Diode | TSC |
| L1 | CDRH3D18-100NC | Power Inductor 10µH 0.9A SMD | Sumida |
| LED1 | 0805KRCT | Red LED 0805 | HB |
| CYCLE, UP, DOWN | 6*6*5 | 12V 50mA Pushbutton | E-LT |

**Table 7: AAT1403 Evaluation Board Bill of Materials (BOM).**

*Serial LED Driver with Filtered PWM and 32-Step S²C Dimming Control*

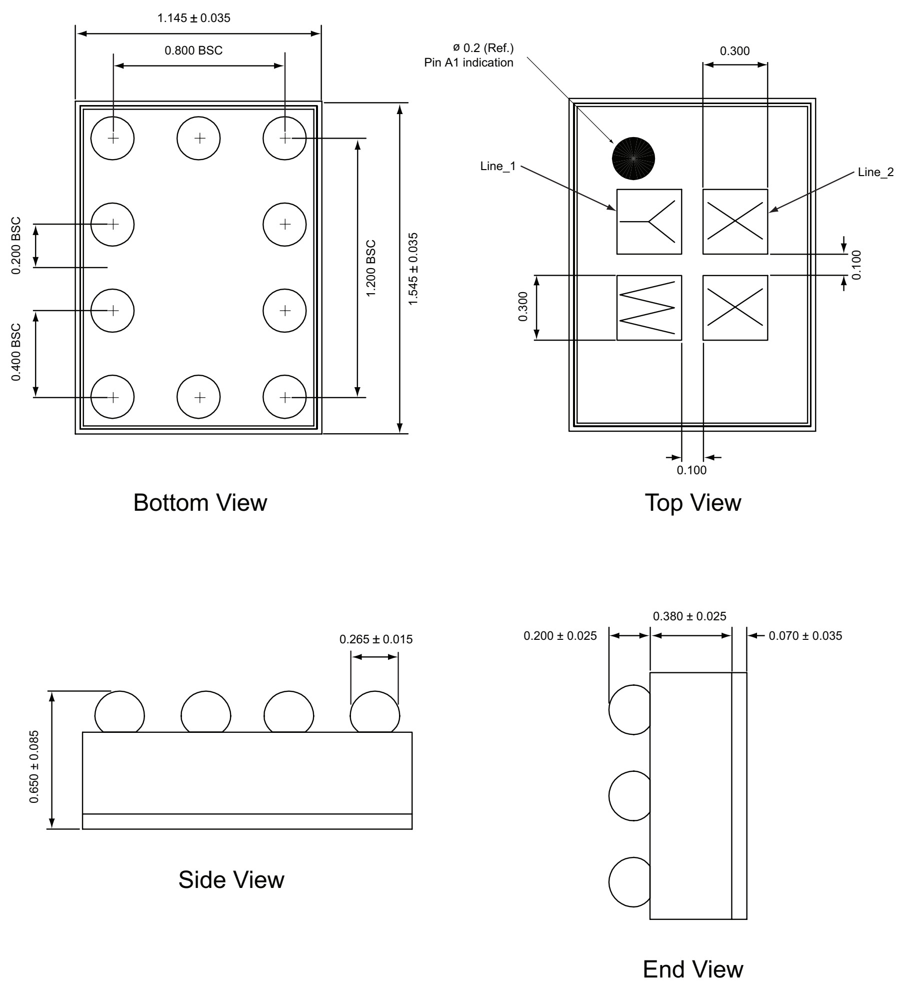
## Ordering Information

| Package | Maximum # of LEDs | Interface | Marking[1] | Part Number (Tape and Reel)[2] |
|---|---|---|---|---|
| WLCSP-10 | 10 | S²C, Filtered PWM | H5YY | **AAT1403IUQ-T1** |

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.

## Package Information

**WLCSP-10**




All dimensions in millimeters.

1. YY = date code.
2. Sample stock is generally held on part numbers listed in **BOLD**.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