AAT3174

High Current, High Efficiency Charge Pump

ChargePump™

General Description

The AAT3174 is a high output current, high efficiency, low noise, low profile charge pump DC/DC converter. The device is ideal for multi-functional LED photo-flash applications where solution cost, size, and efficiency are critical.

The AAT3174 is capable of driving a regulated output current up to 800mA. Output current levels can be easily programmed in 16 steps through AnalogicTech's Simple Serial Control™ (S²Cwire™) interface controlled by a single microcontroller GPIO line. This allows smooth transitions and flexible adjustment of brightness in flash or other lighting modes. The maximum output current can also be set with an external R_{SET} resistor.

The tri-mode (1X/1.5X/2X) operation of the internal charge pump offers excellent power efficiency throughout the output current range for both flash and movie modes. Combined with a low external parts count (two 1µF flying capacitors and two small bypass capacitors at V_{IN} and OUT), the AAT3174 is ideally suited for small battery-powered applications.

The AAT3174 has a thermal management system to protect the device in the event of a short-circuit condition at the output pin. Built-in soft-start circuitry prevents excessive inrush current during start-up. The shutdown feature disconnects the load from V_{IN} and reduces quiescent current to less than 1µA.

The AAT3174 is available in a Pb-free, thermally-enhanced 12-pin 3x3mm TDFN package and is specified over the -40°C to +85°C temperature range.

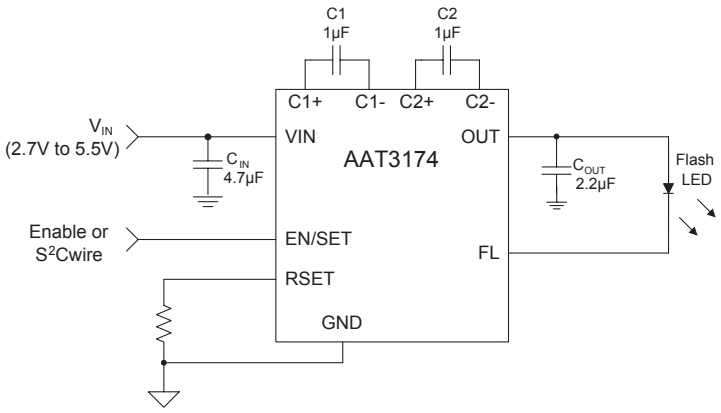
Features

- Up to 800mA Output Current
- Tri-Mode 1X/1.5X/2X in Current Mode
- 16 Current Steps Set by S²Cwire
- External R_{SET} to Set Maximum Current
- <1µA of Shutdown
- Small Application Circuit
- No Inductors
- Automatic Soft Start
- 12-Pin TDFN 3x3mm Package
- -40°C to +85°C Temperature Range

Applications

- Camcorders
- Camera Phones
- Digital Still Cameras
- PDAs and Notebook PCs
- Smart Phones

Typical Application

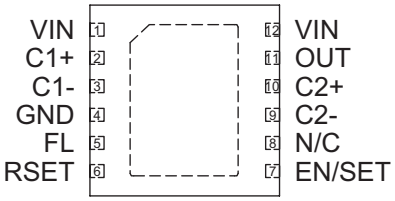


Pin Descriptions

Pin #	Symbol	Function
1	VIN	Input power supply pin. Requires 4.7µF bypass capacitor to ground.
2	C1+	Flying capacitor C1 positive terminal. Connect a 1µF capacitor between C1+ and C1-.
3	C1-	Flying capacitor C1 negative terminal.
4	GND	Ground connection.
5	FL	Controlled current sink. Connect the flash LED cathode to this pin.
6	RSET	Connect resistor here to set maximum output current.
7	EN/SET	Charge pump enable / set input control pin. When in the low state, the AAT3174 is powered down and consumes less than 1µA. When connected to logic high level, the AAT3174 charge pump is active. This pin should not be left floating.
8	N/C	Not connected.
9	C2-	Flying capacitor C2 negative terminal.
10	C2+	Flying capacitor C2 positive terminal. Connect a 1µF capacitor between C2+ and C2-.
11	OUT	Charge pump output. Requires 2.2µF bypass capacitor to ground. Connect to flash LED anode to drive the LED.
12	VIN	Input power supply pin. Requires 4.7µF bypass capacitor to ground.
EP		Exposed paddle (bottom). Connect to GND directly beneath package.

Pin Configuration

TDFN33-12
(Top View)



Absolute Maximum Ratings[1]

T_A = 25°C, unless otherwise noted.

Symbol	Description	Value	Units
V_{IN}	Input Voltage	-0.3 to 6.0	V
V_{EN}	EN to GND Voltage	-0.3 to 6.0	V
$V_{EN(MAX)}$	Maximum EN to Input Voltage	V_{IN} + 0.3	V
I_{OUT}	Maximum Output Current	1000	mA
T_J	Operating Temperature Range	-40 to 150	°C
T_S	Storage Temperature Range	-65 to 150	°C
T_{LEAD}	Maximum Soldering Temperature (at leads, 10 sec)	300	°C

Thermal Information[2]

Symbol	Description	Value	Units
θ_{JA}	Thermal Resistance	50	°C/W
P_D	Maximum Power Dissipation	2.0	mW

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

Electrical Characteristics[1]

C_{IN} = 4.7µF, C_{OUT} = 2.2µF, C_1 = C_2 = 1.0µF; T_A = -40°C to +85°C, unless otherwise noted. Typical values are T_A = 25°C, V_{IN} = 3.6V.

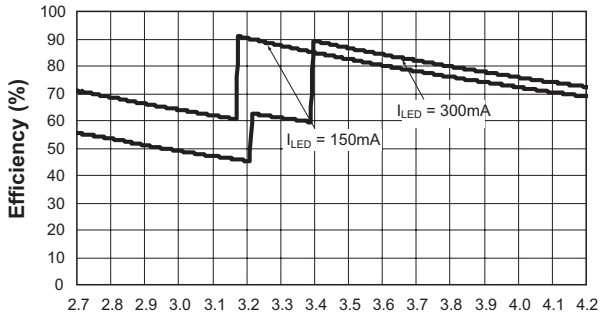
Symbol	Description	Conditions	Min	Typ	Max	Units
Power Supply						
V_{IN}	Input Voltage Range		2.7		5.5	V
I_{CC}	Operating Current	1X, No Load Current		300		µA
		3.0 ≤ V_{IN} ≤ 5.5, 1.5X Mode, No Load Current		2.0	4.0	mA
		3.0 ≤ V_{IN} ≤ 5.5, 2X Mode, No Load Current		3.0	6.0	
$I_{SHDN(MAX)}$	V_{IN} Pin Shutdown Current	EN = 0			1.0	µA
$I_{OUT(MAX)}$[2]	Maximum Output Current	V_F = 3.6V		800		mA
I_{DX}	Output Current Accuracy	Programmed for 600mA; R_{SET} = 187kΩ	540		660	mA
T_{SS}	Soft-Start Time			200		µs
V_{RSET}	R_{SET} Pin Voltage			0.7		V
EN/SET						
$V_{EN(L)}$	Enable Threshold Low	V_{IN} = 2.7V			0.4	V
$V_{EN(H)}$	Enable Threshold High	V_{IN} = 5.5V	1.4			V
$T_{EN/SET\ LO}$	EN/SET Low Time		0.3		60	µs
$T_{EN/SET\ HI}$	Minimum EN/SET High Time			50		ns
$T_{EN/SET\ HI\ MAX}$	Maximum EN/SET High Time				60	µs
T_{OFF}	EN/SET Off Timeout				500	µs
T_{LAT}	EN/SET Latch Timeout				500	µs
Input Current	EN/SET Input Leakage		-1		1	µA

1. The AAT3174 is guaranteed to meet performance specifications from 0°C to 70°C. Specification over the -40°C to +85°C operating temperature range is assured by design, characterization, and correlation with statistical process controls.
2. Mounted on an FR4 board.

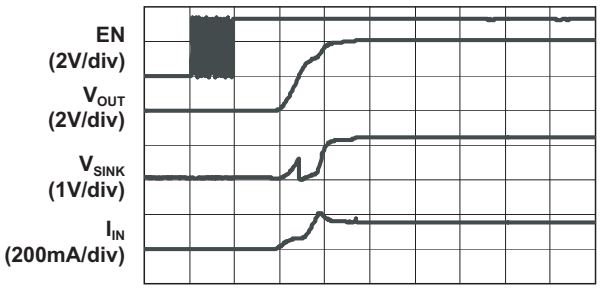
Typical Characteristics

V_{IN} = 3.6V, C_{IN} = 4.7µF, C_{OUT} = 2.2µF, C_1 = C_2 = 1µF, T_A = 25°C, unless otherwise noted.

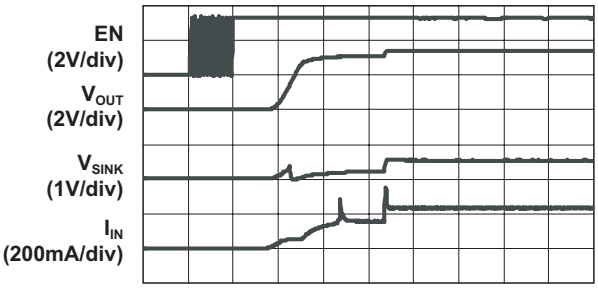
Efficiency vs. Supply Voltage



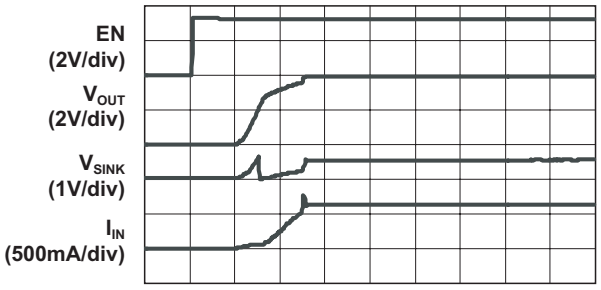
Turn-On to 1X Mode
(V_{IN} = 4.2V; I_{LED} = 150mA)



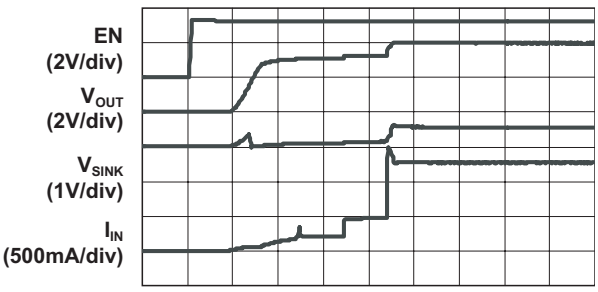
Turn-On to 1.5X Mode
(V_{IN} = 3.2V; I_{LED} = 150mA)



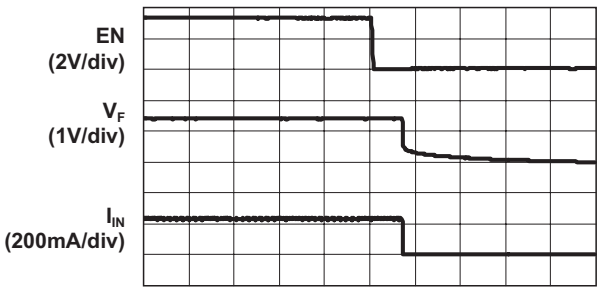
Turn-On to 1X Mode
(V_{IN} = 4.2V; I_{LED} = 600mA)



Turn-On to 2X Mode
(V_{IN} = 3.2V; I_{LED} = 600mA)



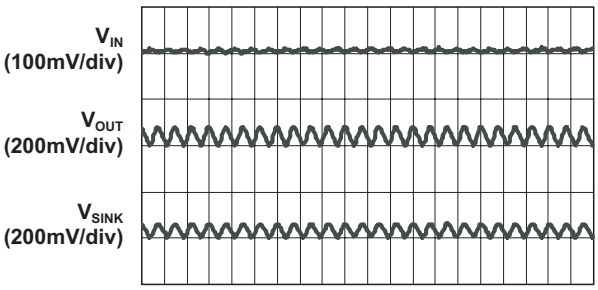
Turn-Off from 1.5X Mode
(V_{IN} = 3.2V; I_{LED} = 150mA)



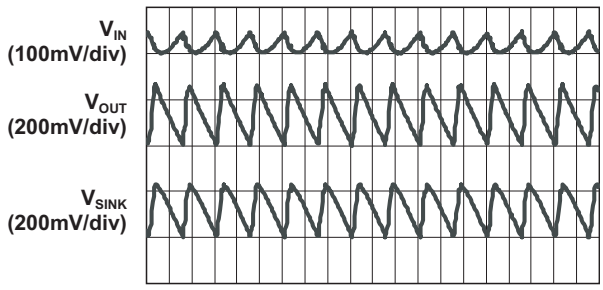
Typical Characteristics

V_{IN} = 3.6V, C_{IN} = 4.7µF, C_{OUT} = 2.2µF, C_1 = C_2 = 1µF, T_A = 25°C, unless otherwise noted.

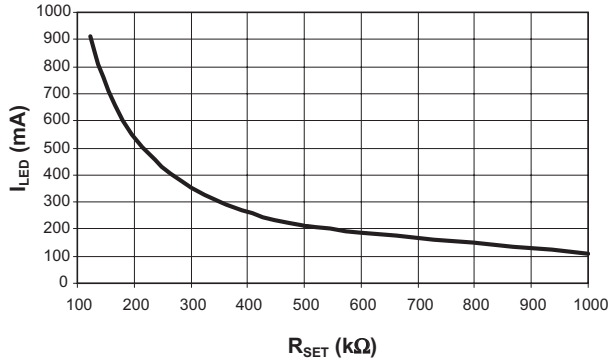
Operating Characteristic
(V_{IN} = 3.3V; 1.5X Mode; I_{LED} = 300mA)



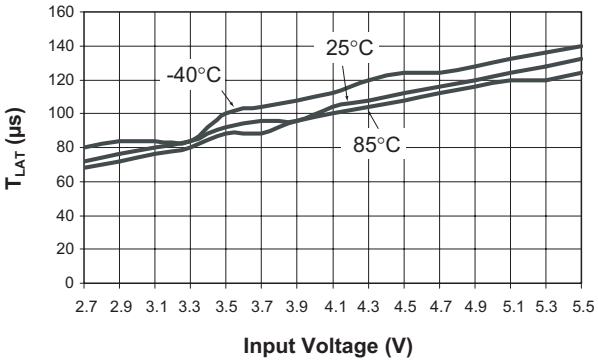
Operating Characteristic
(V_{IN} = 2.9V; 2X Mode; I_{LED} = 300mA)



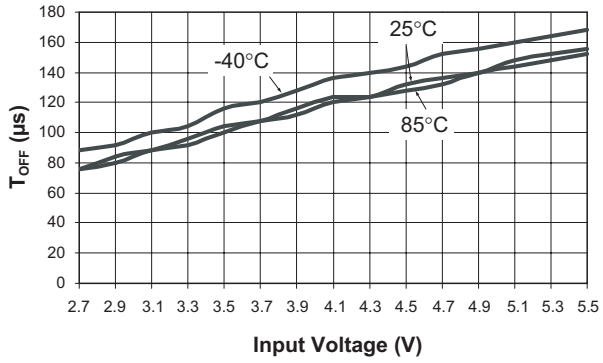
LED Current vs. R_{SET}
(Data = 1)



T_{LAT} vs. V_{IN}



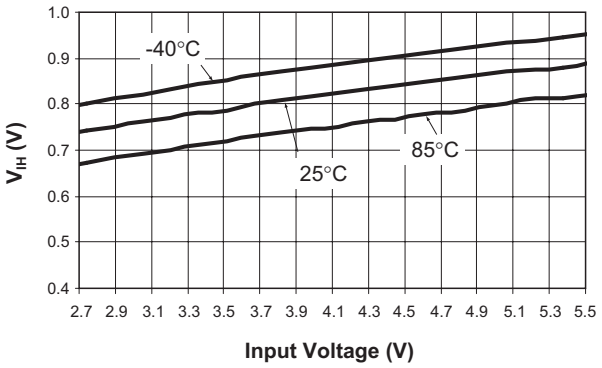
T_{OFF} vs. V_{IN}



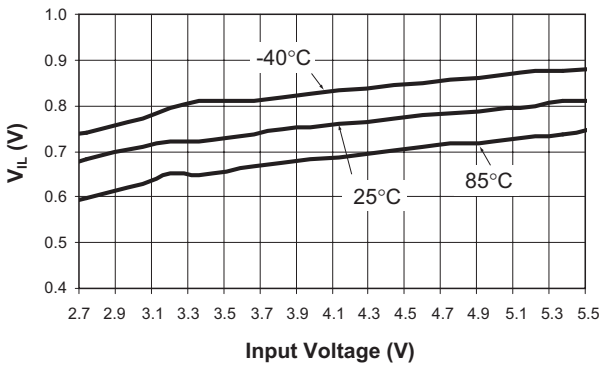
Typical Characteristics

V_{IN} = 3.6V, C_{IN} = 4.7µF, C_{OUT} = 2.2µF, C_1 = C_2 = 1µF, T_A = 25°C, unless otherwise noted.

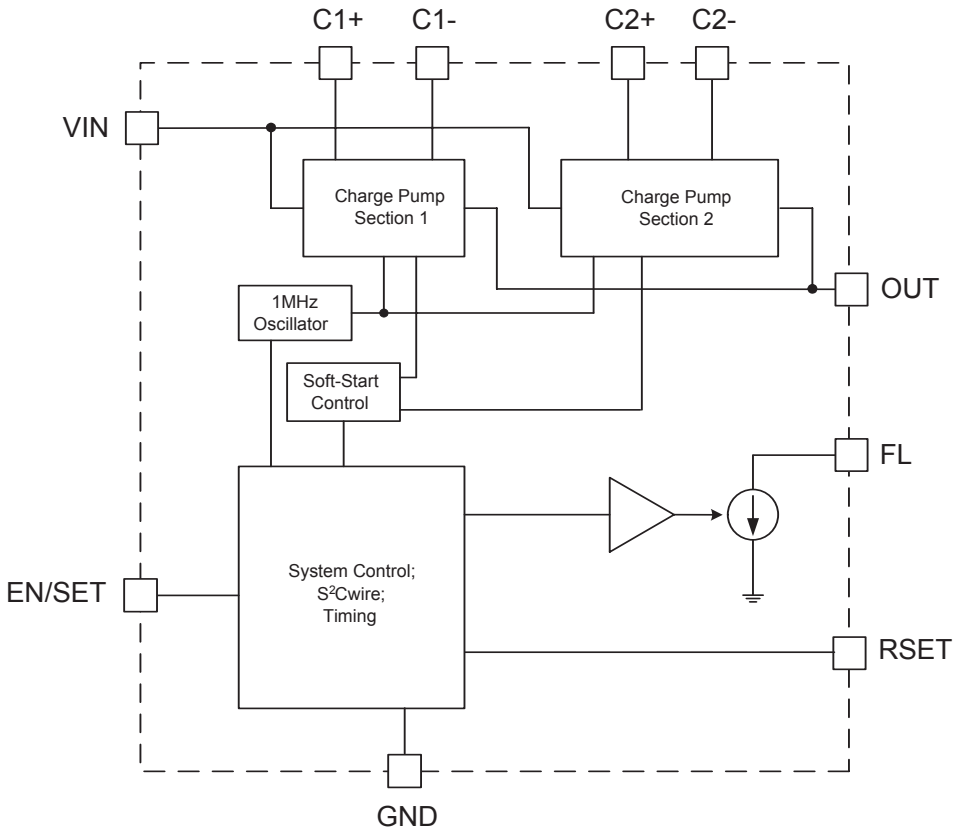
V_{IH} vs. V_{IN} Over Temperature



V_{IL} vs. V_{IN} Over Temperature



Functional Block Diagram



Functional Description

The AAT3174 is a high efficiency, low noise, dual stage tri-mode 1X/1.5X/2X charge pump device intended for photo-flash LED applications. The device requires only four external components: two ceramic capacitors for the charge pump flying capacitors, one ceramic capacitor for C_{IN}, and one ceramic capacitor for C_{OUT}.

The charge pump is designed to deliver regulated load currents up to 800mA. The dual stage charge pump section contains soft-start circuitry to prohibit excessive inrush current during start-up. System efficiency is maximized with a tri-mode, dual stage charge pump topology. The internal clock oscillator at 1MHz allows the use of small external components.

The tri-mode charge pump operation further optimizes power conversion efficiency. Depending upon the variance of load current (at different modes), input voltage, and nominal LED forward voltage, the charge pump will operate in a 1X, 1.5X, or 2X mode to generate the output voltage required to power the load for a given controlled constant current. This results in significant power savings over voltage doubling architectures, especially when the LEDs are also operated at lower current levels in movie, viewing, or flashlight modes.

S²Cwire Serial Interface

The AAT3174 utilizes Analogic Tech's single wire S²Cwire interface to enable/disable the charge pump and adjust the output current at 16 current levels. Each code defines the output current to be a percentage of the maximum current set by the resistor at the R_{SET} pin (see Table 1).

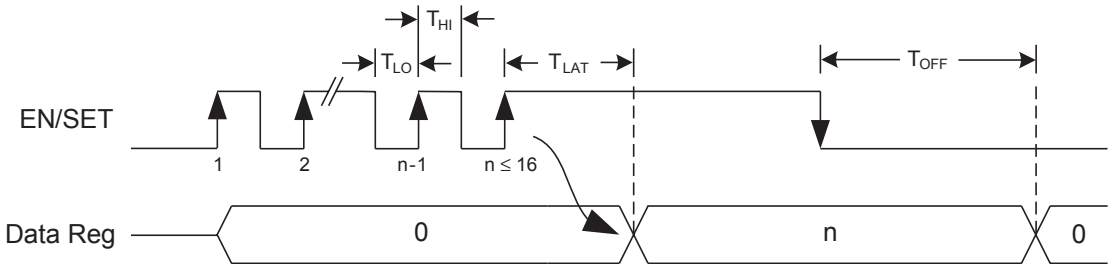
Data	Total Output (% of I_{MAX})
1	100.0
2	89.1
3	79.4
4	70.8
5	63.1
6	56.2
7	50.1
8	44.7
9	39.8
10	35.5
11	31.6
12	28.2
13	25.1
14	22.4
15	20.0
16	0.0

Table 1: Current Level Settings.

The S²Cwire interface records rising edges of the EN/SET pin and decodes them into 16 individual current level settings with Code 1 reserved for maximum current. Once EN/SET has been held in the logic high state for time T_{LAT}, the programmed current is seen at the current source outputs and the internal data register is reset to 0. For subsequent current level programming, the number of rising edges corresponding to the desired code must be entered on the EN/SET pin.

When EN/SET is held low for an amount of time greater than T_{OFF}, the AAT3174 enters into shutdown mode and draws less than 1µA from V_{IN}. Data and address registers are reset to 0 during shutdown.

S²Cwire Serial Interface Timing



Application Information

Flash/Torch Control Using the RSET Pin

An alternative method can be used for flash/torch control that eliminates the need to use the S²Cwire single-wire interface. By using any typical digital I/O port, an additional enable can be created (see Figure 1).

The I/O port output configuration can be any one of open-drain NMOS, open-drain PMOS, or push-pull type. The control will always act as an active-low flash enable or, equivalently, an active-high torch enable (see Table 2).

EN	$\overline{ENFL}$	Mode
0	0	Off
0	1	Off
1	0	Flash
1	1	Torch

Table 2: Flash/Torch Control Modes.

According to I/O port type, the following equations can be used to calculate appropriate resistor values.

For an open-drain NMOS I/O port output configuration, the line is pulled low to GND or left floating, according to state. To calculate the appropriate R_1 and R_2 resistor values, first calculate the R_1 resistor value needed for the desired torch level LED current:

$$R_1 = \frac{600mA \cdot 187k\Omega}{I_{LED}\ (torch)}$$

Next, choose R_2 based on the desired flash level LED current:

$$R_2 = \frac{R_1 \cdot 600mA \cdot 187k\Omega}{R_1 \cdot I_{LED}\ (flash) - 600mA \cdot 187k\Omega}$$

The current and resistance values used in the equations come from the conditions placed on the I_{DX} parameter of the Electrical Characteristics table.

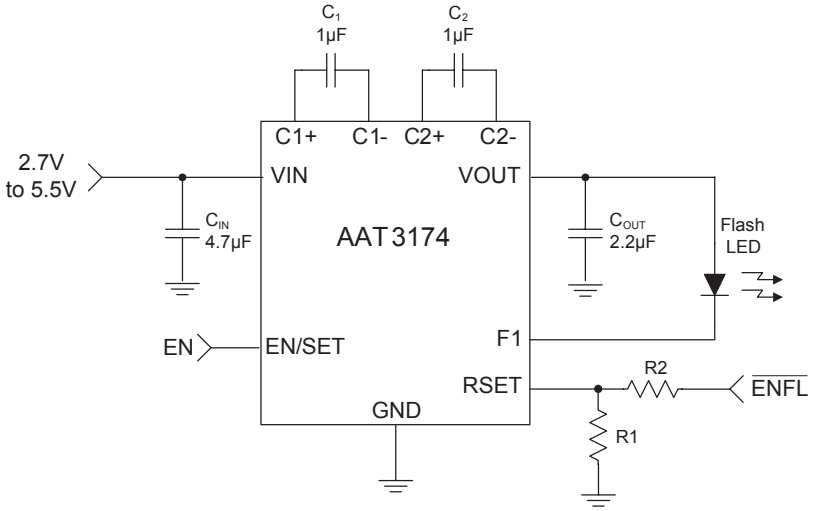


Figure 1: Flash/Torch Control Using the RSET Pin.

For examples of standard 1% values where the LED flash current level is targeted for 700mA, see Table 3.

R1 (kΩ)	R2 (kΩ)	I_{LED} Torch (mA)	I_{LED} Flash (mA)
920	193	122	703
732	205	153	701
649	210	173	707
562	223	200	703

Table 3: Open-Drain I/O Example Resistor Values.

If the I/O port must be configured as an open-drain PMOS type output, the appropriate equations can be generated from these same concepts. As done in the previous example, the necessary values can then be calculated.

As a reference, the equations applicable to the PMOS case are:

$$R_1 = \frac{600mA \cdot 187k\Omega}{I_{LED}\ (flash)}$$

$$R_2 = \frac{\frac{V_{IO}}{0.7} - 1}{\frac{1}{R_1} - \frac{I_{LED}\ (torch)}{600mA \cdot 187k\Omega}}$$

The value to use for V_{IO} must come from the I/O supply voltage used in the system. 0.7V is the typical value of the V_{RSET} parameter found in the Electrical Characteristics.

For a push-pull I/O port output configuration, first calculate the overall R_{SET} value needed for the desired flash level LED current:

$$R_{SET} = \frac{600mA \cdot 187k\Omega}{I_{LED}\ (flash)}$$

Next, choose a reasonable value for R_1. A value that is slightly larger than R_{SET}, calculated from above, is appropriate. Calculate R_2 and then calculate the torch mode current level that results:

$$R_2 = \frac{R_{SET} \cdot R_1}{R_1 - R_{SET}}$$

$$I_{LED}\ (torch) = 600mA \cdot 187k\Omega \cdot \left(\frac{R_2 - R_1}{R_1 \cdot R_2} - \frac{V_{IO}}{0.7V \cdot R_2} \right)$$

Once again, the current and resistance values used in the equations come from the conditions placed on the I_{DX} parameter of the Electrical Characteristics table. 0.7V is the typical value for the V_{RSET} parameter. The value to use for V_{IO} must come from the I/O supply voltage used in the system.

Example standard 1% values are provided in Table 4.

R1 (kΩ)	R2 (kΩ)	I_{LED} Torch (mA)	I_{LED} Flash (mA)
169	1000	95	776
165	1000	111	792
162	1000	124	805
160	1000	132	813

Table 4: Push-Pull I/O Example Resistor Values.

In all of the approaches mentioned, the open-drain NMOS or PMOS type configurations offer the most flexibility for current level selection.

When configured as an output, if the I/O port is only push-pull type, then the equivalent open-drain NMOS can also be realized. To realize this, activate the port as output only when driving the line low. Otherwise, to release the line, set the port to be tri-stated.

Device Power Efficiency

The AAT3174 power conversion efficiency depends on the charge pump mode. By definition, device efficiency is expressed as the output power delivered to the LED divided by the total input power consumed.

$$\eta = \frac{P_{OUT}}{P_{IN}}$$

When the input voltage is sufficiently greater than the LED forward voltage, the device optimizes efficiency by operating in 1X mode. In 1X mode, the device is working as a bypass switch and passing the input supply directly to the output. The power conversion efficiency can be approximated by,

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

Due to the very low 1X mode quiescent current, the input current nearly equals the current delivered to the LED. Further, the low-impedance bypass switch introduces negligible voltage drop from input to output.

The AAT3174 further maintains optimized performance and efficiency by detecting when the input voltage is not sufficient to sustain LED current. The device automatically switches to 1.5X mode when the input voltage drops too low in relation to the LED forward voltage.

In 1.5X mode, the output voltage can be boosted to 3/2 the input voltage. The 3/2 conversion ratio introduces a corresponding 1/2 increase in input current. For ideal conversion, the 1.5X mode efficiency is given by:

$$\eta = \frac{V_F \cdot I_{LED}}{V_{IN} \cdot 1.5I_{IN}} = \frac{V_F}{1.5 \cdot V_{IN}}$$

Similarly, when the input falls further, such that 1.5X mode can no longer sustain LED current, the device will automatically switch to 2X mode. In 2X mode, the output voltage can be boosted to twice the input voltage. The doubling conversion ratio introduces a corresponding doubling of the input current. For ideal conversion, the 2X mode efficiency is given by:

$$\eta = \frac{V_F \cdot I_{LED}}{V_{IN} \cdot 2I_{IN}} = \frac{V_F}{2 \cdot V_{IN}}$$

LED Selection

The AAT3174 is designed to drive high-intensity white LEDs. It is particularly suitable for LEDs with an operating forward voltage in the range of 4.2V to 1.5V.

The charge pump device can also drive other loads that have similar characteristics to white LEDs. For various load types, the AAT3174 provides a high-current, programmable ideal constant current source.

Capacitor Selection

Careful selection of the four external capacitors C_{IN}, C_1, C_2, and C_{OUT} is important because they will affect turn-on time, output ripple, and transient performance. Optimum performance will be obtained when low equivalent series resistance (ESR) ceramic capacitors are used. In general, low ESR may be defined as less than 100mΩ. A value of 1µF for the flying capacitors is a good starting point when choosing capacitors. If the LED current sinks are only programmed for light current levels, then the capacitor size may be decreased.

Ceramic composition capacitors are highly recommended over all other types of capacitors for use with the AAT3174. Ceramic capacitors offer many advantages over their tantalum and aluminum electrolytic counterparts. A ceramic capacitor typically has very low ESR, is lowest cost, has a smaller PCB footprint, and is non-polarized. Low ESR ceramic capacitors help maximize charge pump transient response. Since ceramic capacitors are non-polarized, they are not prone to incorrect connection damage.

Equivalent Series Resistance

ESR is an important characteristic to consider when selecting a capacitor. ESR is a resistance internal to a capacitor that is caused by the leads, internal connections, size or area, material composition, and ambient temperature. Capacitor ESR is typically measured in milliohms for ceramic capac-

itors and can range to more than several ohms for tantalum or aluminum electrolytic capacitors.

Ceramic Capacitor Materials

Ceramic capacitors less than 0.1µF are typically made from NPO or C0G materials. NPO and C0G materials generally have tight tolerance and are very stable over temperature. Larger capacitor values are usually composed of X7R, X5R, Z5U, or Y5V dielectric materials. Large ceramic capacitors are often available in lower-cost dielectrics, but capacitors greater than 4.7µF are not typically required for AAT3174 applications.

Capacitor area is another contributor to ESR. Capacitors that are physically large will have a lower ESR when compared to an equivalent material smaller capacitor. These larger devices can improve circuit transient response when compared to an equal value capacitor in a smaller package size.

Thermal Protection

The AAT3174 has a thermal protection circuit that will shut down the charge pump if the die temperature rises above the thermal limit, as is the case during a short-circuit of the OUT pin.

PCB Layout

To achieve adequate electrical and thermal performance, careful attention must be given to the PCB layout. In the worst-case operating condition, the chip must dissipate considerable power at full load. Adequate heat-sinking must be achieved to ensure intended operation.

Figure 2 illustrates an example of an adequate PCB layout. The bottom of the package features an exposed metal paddle. The exposed paddle acts, thermally, to transfer heat from the chip and, electrically, as a ground connection.

The junction-to-ambient thermal resistance (θ_{JA}) for the package can be significantly reduced by following a couple of important PCB design guidelines.

The PCB area directly underneath the package should be plated so that the exposed paddle can be mated to the top layer PCB copper during the re-flow process. This area should also be connected to the top layer ground pour when available. Further, multiple copper plated thru-holes should be used to electrically and thermally connect the top surface paddle area to additional ground plane(s) and/or the bottom layer ground pour.

The chip ground is internally connected to both the paddle and the GND pin. The GND pin conducts large currents and it is important to minimize any differences in potential that can result between the GND pin and exposed paddle. It is good practice to connect the GND pin to the exposed paddle area using a trace as shown in Figure 2.

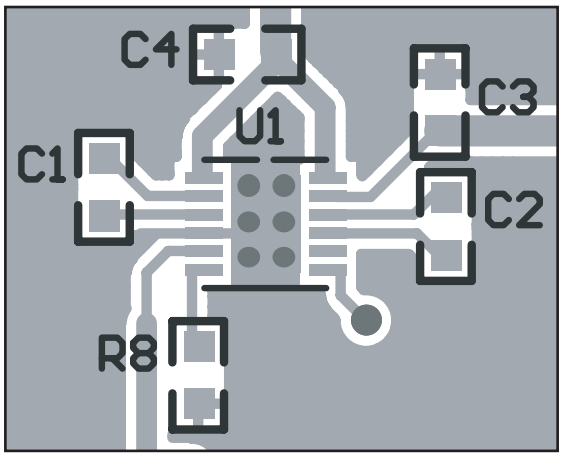


Figure 2: Example PCB Layout.

The flying capacitors C1 and C2 should be connected close to the chip. Trace length should be kept short to minimize path resistance and potential coupling. The input and output capacitors should also be placed as close to the chip as possible.

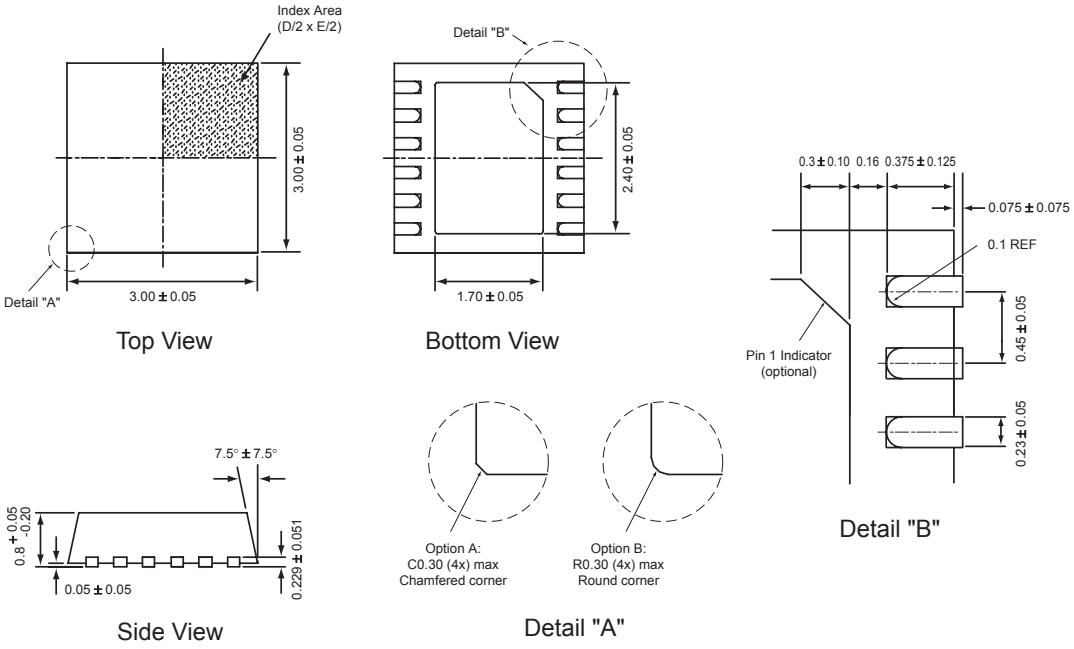
Ordering Information

Package	Marking[1]	Part Number (Tape and Reel)[2]
TDFN33-12	RSXYY	**AAT3174IWP-T1**

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

Package Information

TDFN33-12



All dimensions in millimeters.

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

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