AAT3153

High Efficiency 1X/1.5X/2X Charge Pump For White LED Applications

ChargePump™

General Description

The AAT3153 is a low noise, constant frequency charge pump DC/DC converter that uses a tri-mode load switch (1X), fractional (1.5X), and doubling (2X) conversion to maximize efficiency for white LED applications. The AAT3153 is capable of driving six LED channels from a 2.7V to 5.5V input. The current sinks may be operated individually or in parallel for driving higher current LEDs. A low external parts count (two 1µF flying capacitors and two small 1µF capacitors at V_{IN} and V_{OUT}) makes this part ideally suited for small, battery-powered applications.

AnalogicTech's S²Cwire™ (Simple Serial Control™) serial digital input is used to enable, disable, and set current for each LED with eight settings (20mA down to 50µA) including main and sub-display group control. The AAT3153 consumes extremely low current internally (50µA typical) at light load for optimized efficiency.

Each output of the AAT3153 is equipped with built-in protection for V_{OUT} short-circuit and auto-disable for load short-circuit conditions. Built-in soft-start circuitry prevents excessive inrush current during start-up. A low current shutdown feature disconnects the load from V_{IN} and reduces quiescent current to less than 1µA.

The AAT3153 is available in a Pb-free, space-saving, thermally-enhanced 16-pin 4x4mm QFN package.

Features

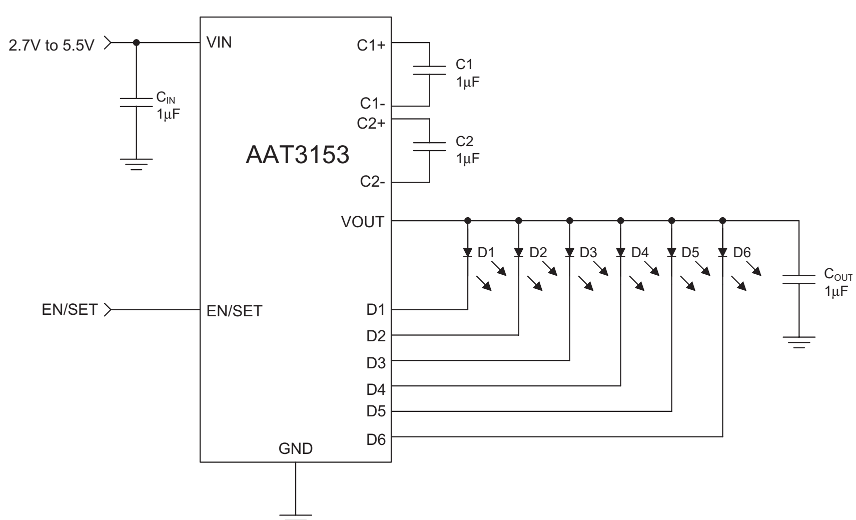
- V_{IN} Range: 2.7V to 5.5V
- Fully Programmable Current with Single Wire
  - Eight-Step Current: 20mA to 50µA
  - Individual Main-Sub Group Control
  - Low I_Q (50µA) at Light Load
- Tri-Mode 1X, 1.5X, and 2X Charge Pump for Maximum Efficiency and V_F Coverage
- Drives Up to Six LED Channels
- No Inductors, Low Noise Operation
- 1MHz Constant Switching Frequency
- Small Application Circuit
- Built-In Thermal Protection
- Built-In Auto-Disable for Short-Circuit
- Automatic Soft Start
- I_Q <1µA in Shutdown
- Thermally-Enhanced 4x4mm 16-Pin QFN Package

Applications

- Color (RGB) Lighting
- Programmable Current Sinks
- White LED Backlighting
- White Photo Flash for Digital Still Cameras

Preliminary Information

Typical Application

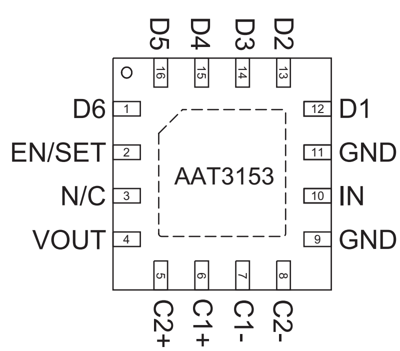


Pin Descriptions

Pin #	Symbol	Function
1	D6	Current sink input #6.
2	EN/SET	S²Cwire serial interface control pin.
3	N/C	No connection.
4	VOUT	Charge pump output to drive load circuit. Requires 1µF capacitor connected between this pin and ground.
5	C2+	Flying capacitor 2 positive terminal. Connect a 1µF capacitor between C2+ and C2-.
6	C1+	Flying capacitor 1 positive terminal. Connect a 1µF capacitor between C1+ and C1-.
7	C1-	Flying capacitor 1 negative terminal.
8	C2-	Flying capacitor 2 negative terminal.
9, 11	GND	Ground.
10	IN	Input power supply. Requires 1µF capacitor connected between this pin and ground.
12	D1	Current sink input #1.
13	D2	Current sink input #2.
14	D3	Current sink input #3.
15	D4	Current sink input #4.
16	D5	Current sink input #5.
EP		Exposed paddle (bottom); connect to GND directly beneath package.

Pin Configuration

QFN44-16
(Top View)



Absolute Maximum Ratings[1]

Symbol	Description	Value	Units
V_{IN}	Input Voltage	-0.3 to 6	V
$V_{EN/SET}$	EN/SET to GND Voltage	-0.3 to V_{IN} + 0.3	V
I_{OUT}[2]	Maximum DC Output Current	180	mA
T_J	Operating Junction Temperature Range	-40 to 150	°C
T_{LEAD}	Maximum Soldering Temperature (at leads, 10 sec)	300	°C

Thermal Information[3]

Symbol	Description	Value	Units
P_D	Maximum Power Dissipation[4]	2.0	W
θ_{JA}	Maximum Thermal Resistance	50	°C/W

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. Based on long-term current density limitation.
3. Mounted on an FR4 board.
4. Derate 6.25mW/°C above 25°C.

Electrical Characteristics[1]

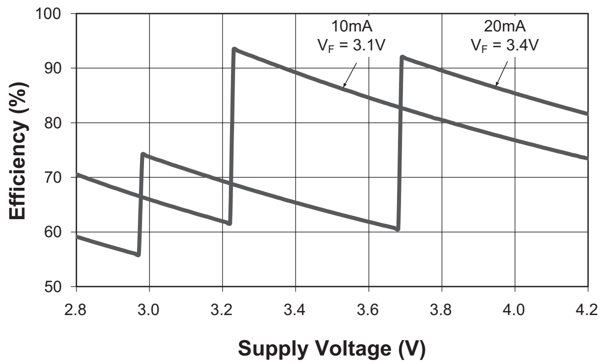
$C_{IN} = C_{OUT} = C_1 = C_2 = 1.0\mu F$; T_A = -40°C to +85°C, unless otherwise noted.
Typical values are T_A = 25°C, V_{IN} = 3.6V.

Symbol	Description	Conditions	Min	Typ	Max	Units
Input Power Supply						
V_{IN}	Operation Range		2.7		5.5	V
I_{CC}	Operating Current	1X Mode, 3.0 ≤ V_{IN} ≤ 5.5, Active, No Load Current		0.3	1	mA
		1.5X Mode, 3.0 ≤ V_{IN} ≤ 5.5, Active, No Load Current		1	3	mA
		2X Mode, 3.0 ≤ V_{IN} ≤ 5.5, Active, No Load Current		2.0	3.7	mA
		50µA Setting, 1X Mode		50		µA
I_{SHDN}	Shutdown Current	EN/SET = 0			1	µA
I_{DX}	I_{SINK} Average Current Accuracy	I_{SET} = 30mA, T_A = 25°C	18	20	22	mA
$I_{(D-Match)}$	Current Matching Between Any Two Current Sink Inputs[2, 3]	V_F:D1:D4 = 3.6V		0.5		%
V_{TH}	1X to 1.5X or 1.5X to 2X Transition Threshold at Any I_{SINK} Pin			150		mV
Charge Pump Section						
T_{SS}	Soft-Start Time			100		µs
F_{CLK}	Clock Frequency			1000		kHz
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		75	µs
T_{EN/SET_HI_MIN}	Minimum EN/SET High Time			50		ns
T_{EN/SET_HI_MAX}	Maximum EN/SET High Time				75	µs
T_{OFF}	EN/SET Off Timeout				500	µs
T_{LAT}	EN/SET Latch Timeout				500	µs
$I_{EN/SET}$	EN/SET Input Leakage		-1		1	µA

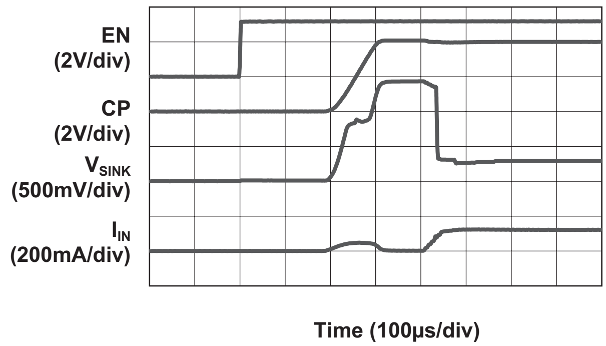
1. The AAT3153 is guaranteed to meet performance specifications over the -40°C to +85°C operating temperature range and is assured by design, characterization, and correlation with statistical process controls.
2. Current matching is defined as the deviation of any sink current from the average of all active channels.
3. Specification applies only to the tri-mode charge pump.

Typical Characteristics

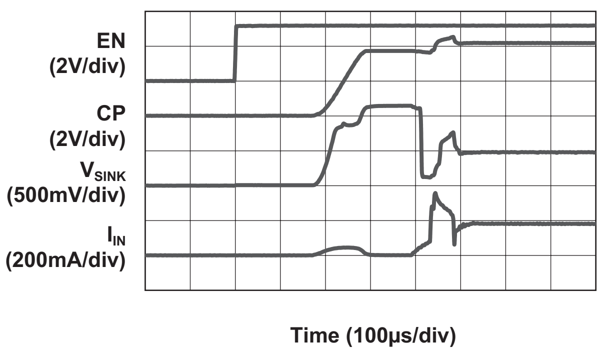
Efficiency vs. Supply Voltage



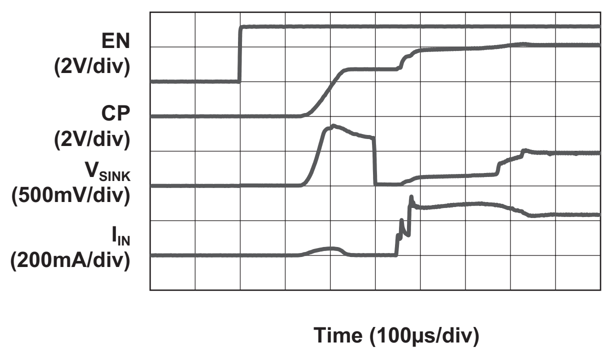
Turn-On to 1X Mode
(V_{IN} = 4.2V; 20mA Load)



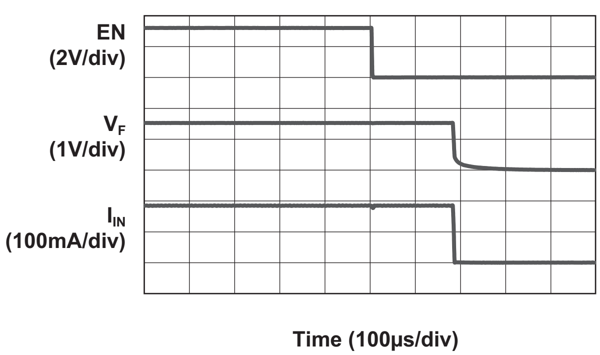
Turn-On to 1.5X Mode
(V_{IN} = 3.8V; 20mA Load)



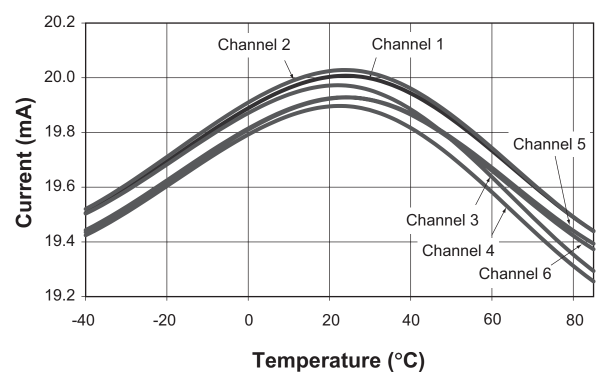
Turn-On to 2X Mode
(V_{IN} = 2.8V; 20mA Load)



Turn-Off from 1.5X Mode
(V_{IN} = 3.5V; 20mA Load)

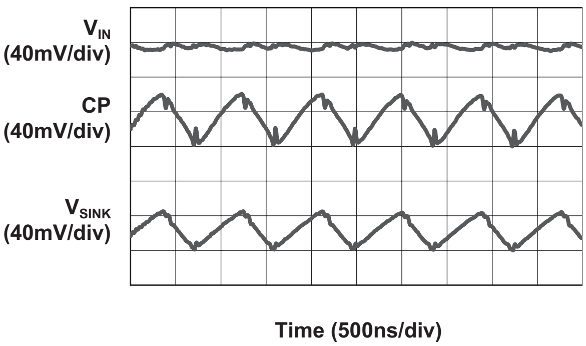


Current Matching vs. Temperature

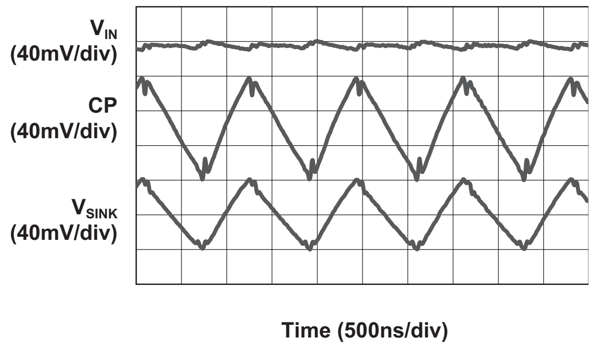


Typical Characteristics

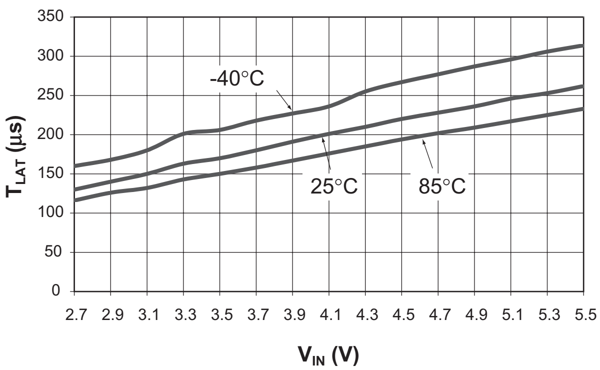
Load Characteristics
(V_{IN} = 4.0V; 1.5X Mode; 20mA Load)



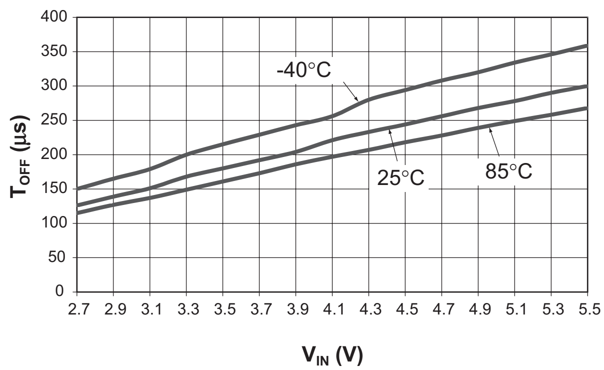
Load Characteristics
(V_{IN} = 3.1V; 2X Mode; 20mA Load)



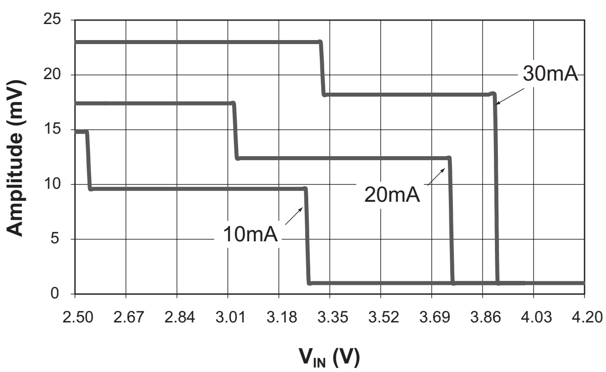
T_{LAT} vs. V_{IN}



T_{OFF} vs. V_{IN}

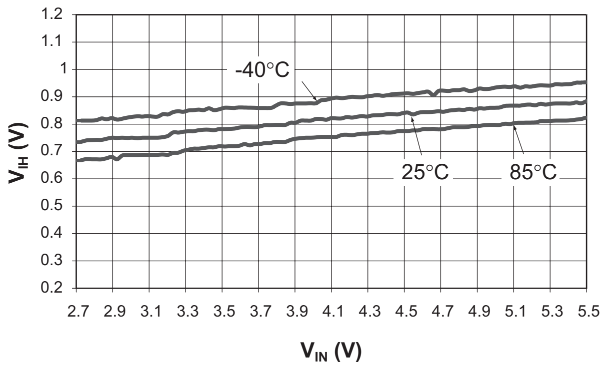


Input Ripple vs. V_{IN}

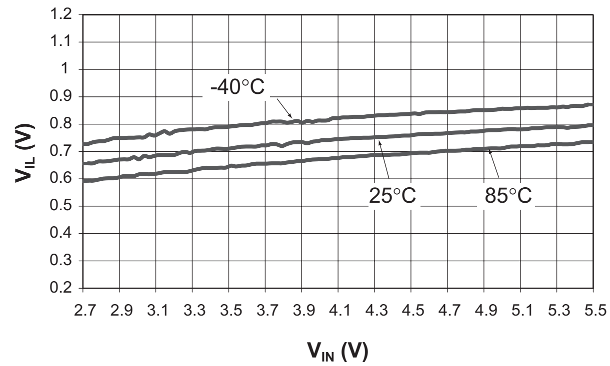


Typical Characteristics

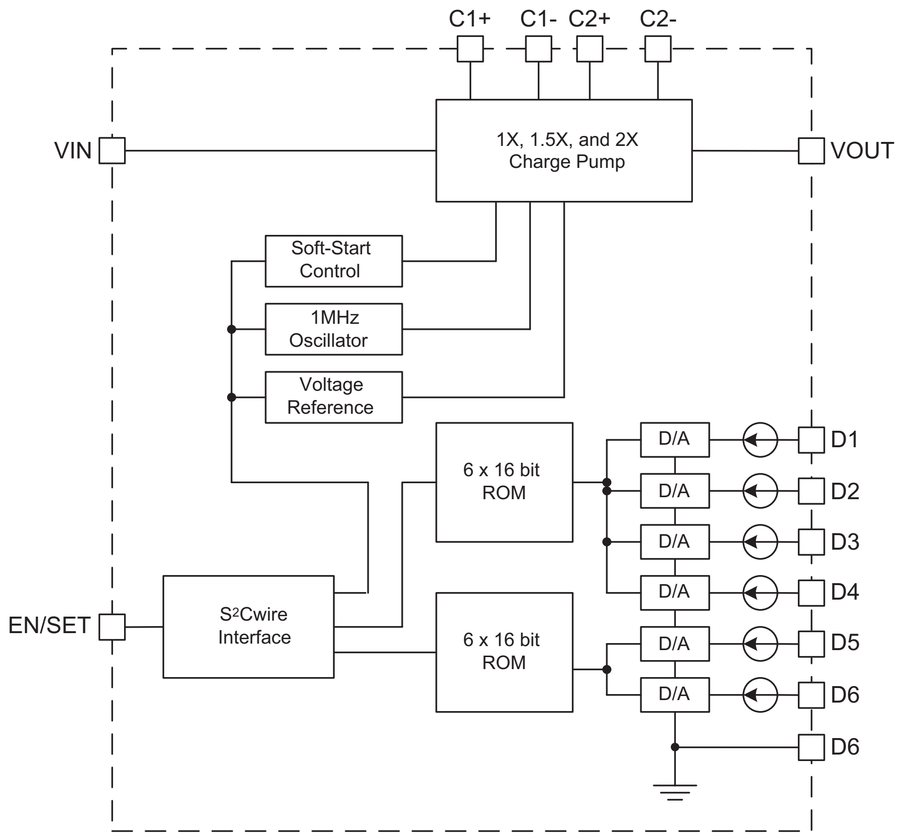
V_{IH} vs. V_{IN}



V_{IL} vs. V_{IN}



Functional Block Diagram



Functional Description

The AAT3153 is a tri-mode load switch (1X) and high efficiency (1.5X or 2X) charge pump device intended for white LED backlight applications. To maximize power conversion efficiency, an internal sensing circuit monitors the voltage required on each constant current sink input and sets the load switch and charge pump modes based on the input battery voltage and the current sink input voltage. As the battery discharges over time, the AAT3153 charge pump is enabled when any of the four current sink inputs near dropout. The charge pump initially starts in 1.5X mode. If the charge pump output drops enough for any current source output to become close to dropout, the charge pump will automatically transition to 2X mode. The AAT3153 requires only four external components: two 1µF ceramic capacitors for the charge pump flying capacitors (C_1 and C_2), one 1µF ceramic input capacitor (C_{IN}), and one 0.33µF to 1µF ceramic charge pump output capacitor (C_{OUT}).

The six constant current sink inputs (D1 to D6) can drive six individual LEDs with a maximum current of 20mA each. The unused sink inputs must be connected to V_{OUT}, otherwise the part will operate only in 2X charge pump mode. The S^2Cwire serial interface enables the AAT3153 and sets the current sink magnitudes. S^2Cwire addressing allows independent control of two groups of current sink input: D1-D4 and D5-D6.

Constant Current Output Level Settings

The constant current sink levels for D1 to D6 are set via the serial interface. No PWM (pulse width modulation) or additional control circuitry are needed to control LED brightness. This feature greatly reduces the burden on a microcontroller or system IC to manage LED or display brightness, allowing the user to "set it and forget it." With its high-speed serial interface (up to 1MHz data rate), the input sink current of the AAT3153 can be changed successively to brighten or dim LEDs, giving the users real-time control of LED brightness. Because the inputs D1 to D6 are true independent constant current sinks, the voltage observed on any single given input will be determined by the actual forward voltage (V_F) for the LED being driven.

S^2Cwire Serial Interface

The current sink input magnitude on the AAT3153 is controlled by AnalogicTech's S^2Cwire serial interface. The interface records rising edges of the EN/SET pin and decodes them into 16 different states, as indicated in Table 1. There are four brightness levels for the main or sub-display group with the possibility of individually turning ON or OFF each group. To further optimize power efficiency, the AAT3153 also offers four low-current levels for dim LED operation (Data 13 through 16). During this low-current mode, the internal supply current reduces to only 50µA typical.

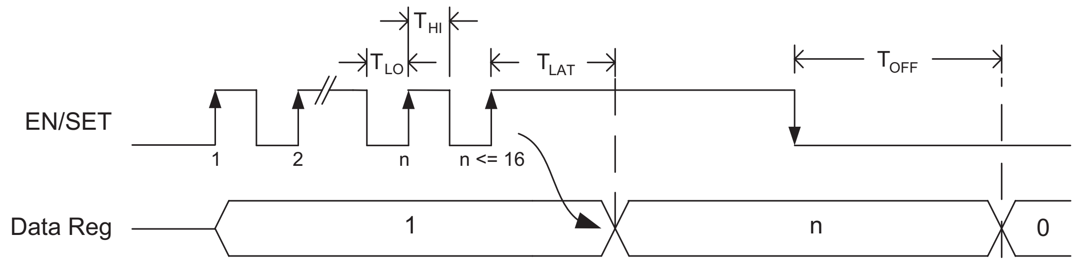
The S^2Cwire serial interface has flexible timing. Data can be clocked-in at speeds greater than 1MHz, or much slower, such as 15kHz. After data is submitted, EN/SET is held high to latch the data. Once EN/SET has been held in the logic high state for time T_{LAT}, the programmed current becomes active and the internal data register is reset to zero. 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 AAT3153 enters into shutdown mode and draws less than 1µA from V_{IN}. The internal data register is reset to zero during shutdown.

Data	Main Group (D1-D4) I_{OUT} (mA)	Sub Group (D5-D6) I_{OUT} (mA)
1	20	20
2	14	14
3	10	10
4	7	7
5	20	0
6	14	0
7	10	0
8	7	0
9	0	20
10	0	14
11	0	10
12	0	7
13	0.05	0.05
14	0.5	0.5
15	1	1
16	2	2

Table 1: AAT3153 Current Settings.

S²Cwire Serial Interface Timing



Auto-Disable Feature

The AAT3153 is equipped with an auto-disable feature for each LED channel. After the IC is enabled and started up, a test current of 150µA (typical) is forced through each sink channel. The channel will be disabled if the voltage of that particular SINK pin does not drop to certain threshold. This feature is very convenient for disabling an unused channel or during an LED fail short event.

Thermal Protection

The AAT3153 has a built-in 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 V_{OUT} pin.

Applications Information

LED Selection

Although the AAT3153 is specifically intended for driving white LEDs, the device can also be used to drive most types of LEDs with forward voltage specifications ranging from 2.0V to 4.7V. LED applications may include main and sub-LCD display backlighting, camera photo-flash applications, color (RGB) LEDs, infrared (IR) diodes for remotes, and other loads benefiting from a controlled output current generated from a varying input voltage. Since the D1 to D6 input current sinks are matched with negligible voltage dependence, the LED brightness will be matched regardless of the specific LED forward voltage (V_F) levels. In some instances (e.g., in high luminous output applications such as photo flash), it may be necessary to drive high-V_F type LEDs. The low-dropout current sinks in the AAT3153 make it capable of driving LEDs with forward voltages as high as 4.7V at full current from an input supply as low as 3.0V. Outputs can be paralleled to drive high-current LEDs without complication.

Device Switching Noise Performance

The AAT3153 operates at a fixed frequency of approximately 1MHz to control noise and limit harmonics that can interfere with the RF operation of cellular telephone handsets or other communication devices. Back-injected noise appearing on the input pin of the charge pump is 20mV peak-to-peak, typically ten times less than inductor-based DC/DC boost converter white LED backlight solutions. The AAT3153 soft-start feature prevents noise transient effects associated with inrush currents during start-up of the charge pump circuit.

Power Efficiency and Device Evaluation

The charge pump efficiency discussion in the following sections only accounts for the efficiency of the charge pump section itself. Due to the unique circuit architecture and design of the AAT3153, it is very difficult to measure efficiency in terms of a percent value comparing input power over output power.

Since the AAT3153 inputs are pure constant current sinks and typically drive individual loads, it is difficult to measure the output voltage for a given input (D1 to D6) to derive an overall output power measurement. For any given application, white LED forward voltage levels can differ, yet the load drive current will be maintained as a constant.

This makes quantifying output power a difficult task when taken in the context of comparing to other white LED driver circuit topologies. A better way to quantify total device efficiency is to observe the total input power to the device for a given LED current drive level. The best white LED driver for a given application should be based on trade-offs of size, external component count, reliability, operating range, and total energy usage...*not just % efficiency.*

The AAT3153 efficiency may be quantified under very specific conditions and is dependent upon the input voltage versus the output voltage seen across the loads applied to inputs D1 through D6 for a given constant current setting. Depending on the combination of V_{IN} and voltages sensed at the current sinks, the device will operate in load switch mode. When any one of the voltages sensed at the current sinks nears dropout, the device will operate in 1.5X or 2X charge pump mode. Each of these modes will yield different efficiency values. Refer to the following two sections for explanations for each operational mode.

Load Switch Mode Efficiency

The AAT3153 load switch mode is operational at all times and functions alone to enhance device power conversion efficiency when V_{IN} is greater than the voltage across the load. When in load switch mode, the voltage conversion efficiency is defined as output power divided by input power:

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

The expression to define the ideal efficiency (η) can be rewritten as:

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times I_{OUT}} = \frac{V_{OUT}}{V_{IN}}$$

-or-

$$\eta(\%) = 100\left(\frac{V_{OUT}}{V_{IN}}\right)$$

Charge Pump Section Efficiency

The AAT3153 contains a fractional charge pump that will boost the input supply voltage when V_{IN} is less than the voltage required on the constant current sink inputs. The efficiency (η) can be simply defined as a linear voltage regulator with an effective output voltage that is equal to one and one half or two times the input voltage. Efficiency (η) for an ideal 1.5X charge pump can typically be expressed as the output power divided by the input power.

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

In addition, with an ideal 1.5X charge pump, the output current may be expressed as 2/3 of the input current. The expression to define the ideal efficiency (η) can be rewritten as:

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times 1.5I_{OUT}} = \frac{V_{OUT}}{1.5V_{IN}}$$

-or-

$$\eta(\%) = 100\left(\frac{V_{OUT}}{1.5V_{IN}}\right)$$

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 all four capacitors is a good starting point when choosing capacitors. If the LED current sources are only programmed for light current levels, then the capacitor size may be decreased.

Capacitor Characteristics

Ceramic composition capacitors are highly recommended over all other types of capacitors for use with the AAT3153. Ceramic capacitors offer many advantages over their tantalum and aluminum electrolytic counterparts. A ceramic capacitor has very low ESR, is lowest cost, has a smaller PCB footprint, and is non-polarized. Low ESR ceramic capacitors help to 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 capacitors 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 (i.e., greater than 2.2µF) are often available in low-cost Y5V and Z5U dielectrics, but capacitors greater than 1µF are not typically required for AAT3153 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.

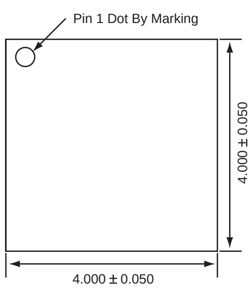
Ordering Information

Package	Marking[1]	Part Number (Tape and Reel)[2]
QFN44-16		AAT3153ISN-T1

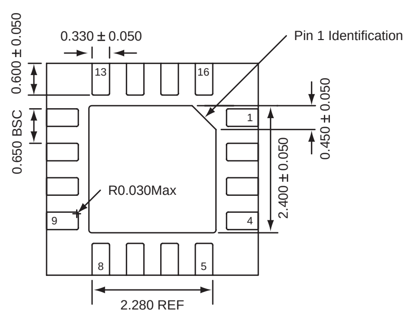
All AnalogicTech products are offered in Pb-free packaging. The term "Pb-free" means semiconductor products that are in compliance with current RoHS standards, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. For more information, please visit our website at http://www.analogictech.com/pbfree.

Package Information

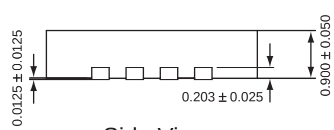
QFN44-16



Top View



Bottom View



Side View

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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