AAT3134

High Efficiency 1X/1.5X Fractional Charge Pump for White LED Applications

General Description

The AAT3134 is a low noise, constant frequency charge pump DC/DC converter that uses a dual mode load switch (1X) and fractional (1.5X) conversion to maximize efficiency for white LED applications. The device can be used to produce current levels up to 20mA in each of its six outputs to drive LEDs from a 2.7V to 5.5V input. Outputs may be operated individually or paralleled for driving higher-current LEDs. A low external parts count (two 1µF flying capacitors and two small 1µF capacitors at V_{IN} and OUT) make the AAT3134 ideally suited for small battery-powered applications.

Skyworks' Simple Serial Control™ (S²Cwire™) interface is used to enable, disable, and set the LED drive current in two groups of four outputs and two outputs with multiple-level, independently-controlled brightness scales. The AAT3134 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. A high charge pump switching frequency enables the use of very small external capacitors. A low-current shutdown feature disconnects the load from V_{IN} and reduces quiescent current to less than 1µA. The AAT3134 is available in a Pb-free 16-pin QFN44 package and is rated over the -40°C to +85°C temperature range.
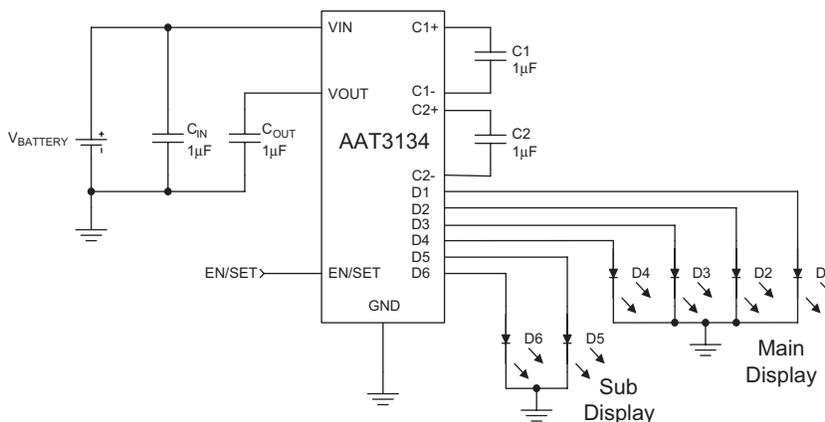
Features

- V_{IN} Range: 2.7V to 5.5V
- <1.0µA of Shutdown
- 1MHz Switching Frequency
- Fully Independent Display Lighting
- Dual Mode 1X and 1.5X Charge Pump for Maximum Efficiency
- Drives Low-V_F and High-V_F Type LEDs
- Up to Six 20mA Outputs
- Multi-Position Brightness Scale with Digital Control
- Low Noise Constant Frequency Operation
- Small Application Circuit
- Regulated Output Current
- Automatic Soft Start
- No Inductors
- 16-Pin QFN44 Package
- -40°C to +85°C Temperature Range

Applications

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

Typical Application

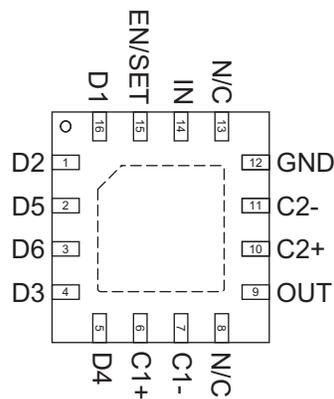Skyworks Solutions, Inc. • Phone [781] 376-3000 • Fax [781] 376-3100 • sales@skyworksinc.com • www.skyworksinc.com

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High Efficiency 1X/1.5X Fractional Charge Pump for White LED Applications

Pin Descriptions

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

Pin Configuration

QFN44-16
(Top View)

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Absolute Maximum Ratings[1]

Symbol	Description	Value	Units
V_{IN}	Input Voltage	-0.3 to 6.0	V
V_{OUT}	Charge Pump Output	-0.3 to 6.0	V
FB, $V_{EN/SET}$	FB or EN/SET to GND Voltage	-0.3 to 6.0	V
$V_{EN/SET(MAX)}$	Maximum EN/SET to Input Voltage	0.3	V
I_{OUT}[2]	Maximum DC Output Current	150	mA
T_J	Operating Junction Temperature Range	-40 to 150	°C

Thermal Information[3]

Symbol	Description	Value	Units
θ_{JA}	Thermal Resistance	50	°C/W
θ_{JC}	Thermal Resistance	15	
P_D	Maximum Power Dissipation	2	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.

High Efficiency 1X/1.5X Fractional Charge Pump for White LED Applications

Electrical Characteristics[1]

V_{IN} = 3.5V, C_{IN} = C_{OUT} = C_1 = C_2 = 1.0µF; T_A = -40°C to +85°C. Unless otherwise noted, typical values are T_A = 25°C.

Symbol	Description	Conditions	Min	Typ	Max	Units
Input Power Supply						
V_{IN}	Operation Range		2.7		5.5	V
I_{CC}	Operating Current	3.0V ≤ V_{IN} ≤ 5.5V, Active, No Load Current		1.8	3.5	mA
I_{SHDN}	Shutdown Current	EN/SET = 0			1.0	µA
$I_{DX(MAX)}$	Maximum Output Current	V_{IN} = 3.6, Code = 32	18	20	22	mA
$I_{(D-Match)}$	Current Matching Between	VD1:D4 = 3.6, V_{IN} = 3.5V		0.5		%
	Any Two Outputs	VD5:VD6 = 3.6, V_{IN} = 3.5V		0.5		
Charge Pump Section						
T_{SS}	Soft-Start Time			200		µs
F_{CLK}	Clock Frequency			1000		kHz
η_{CP}	Charge Pump Section Efficiency	V_{IN} = 3.5V, $I_{OUT(TOTAL)}$ = 120mA, Measured from IN to OUT		93		%
EN/SET						
$V_{EN(L)}$	Enable Threshold Low				0.5	V
$V_{EN(H)}$	Enable Threshold High		1.4			V
$T_{EN/SET\ LO}$	EN/SET Low Time	$V_{EN/SET}$ < 0.5	0.3		75	µs
$T_{EN/SET\ HI}$	Minimum EN/SET High Time	$V_{EN/SET}$ > 1.4		50		ns
T_{OFF}	EN/SET Off Timeout	$V_{EN/SET}$ < 0.5			500	µs
Input Current	EN/SET Input Leakage		-1.0		1.0	µA

1. The AAT3134 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.

Typical Characteristics
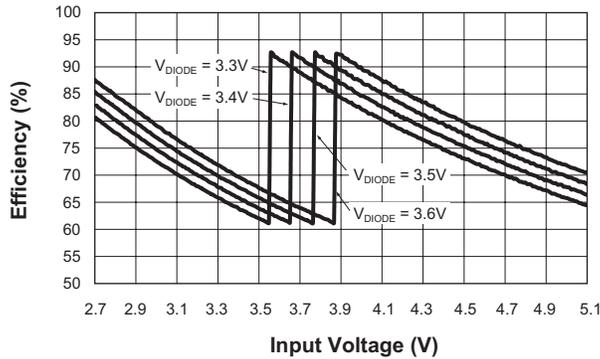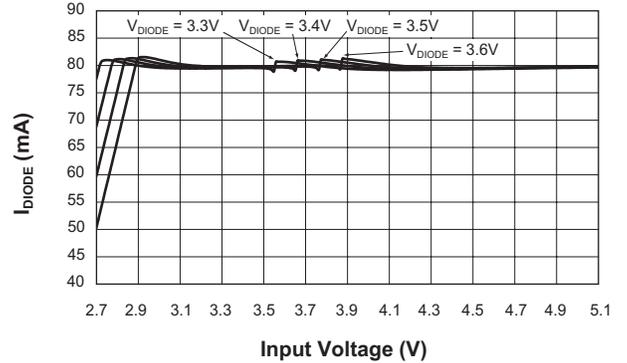
Unless otherwise noted, V_{IN} = 3.5V, C_{IN} = C_{OUT} = C_1 = C_2 = 1µF, T_A = 25°C.
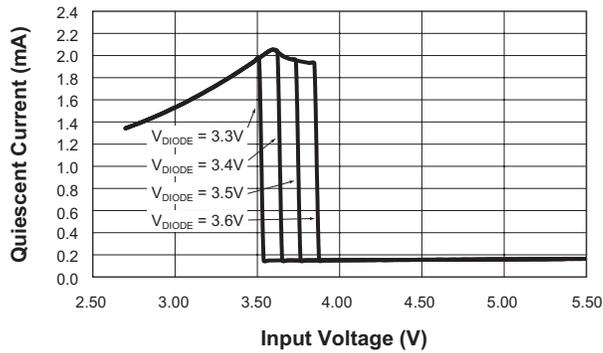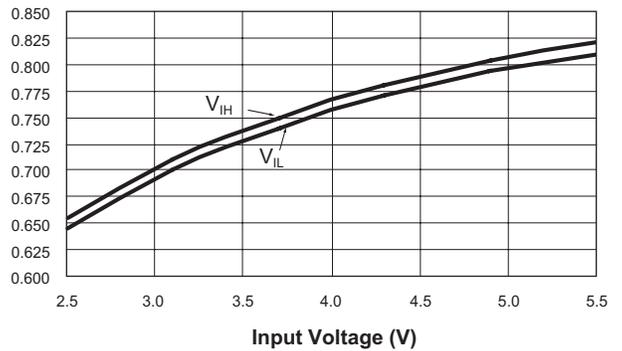
Efficiency vs. Input Voltage
(4x20mA)

I_{DIODE} vs. Input Voltage
(4x20mA)

Quiescent Current vs. Input Voltage
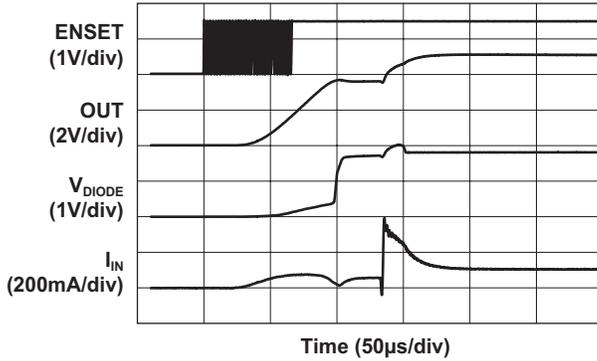

V_{IH} and V_{IL} vs. V_{IN}

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Typical Characteristics

Unless otherwise noted, V_{IN} = 3.5V, C_{IN} = C_{OUT} = C_1 = C_2 = 1µF, T_A = 25°C.

Turn-On to Full-Scale Charge Pump
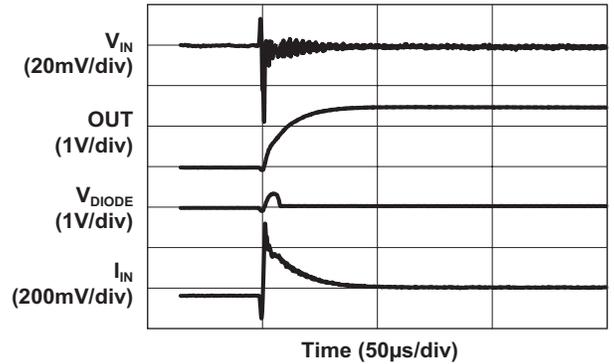
ENSET
(1V/div)

OUT
(2V/div)

V_{DIODE}
(1V/div)

I_{IN}
(200mA/div)

Time (50µs/div)

Turn-On to Full-Scale Load Switch

ENSET
(1V/div)

OUT
(2V/div)

V_{DIODE}
(2V/div)

I_{IN}
(100mA/div)

Time (50µs/div)
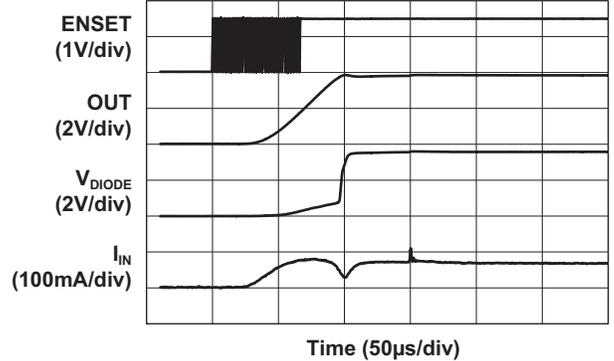
Charge Pump to Load Switch
(80mA)

V_{IN}
(10mV/div)

OUT
(2V/div)

V_{DIODE}
(2V/div)

I_{IN}
(100mA/div)

Time (50µs/div)
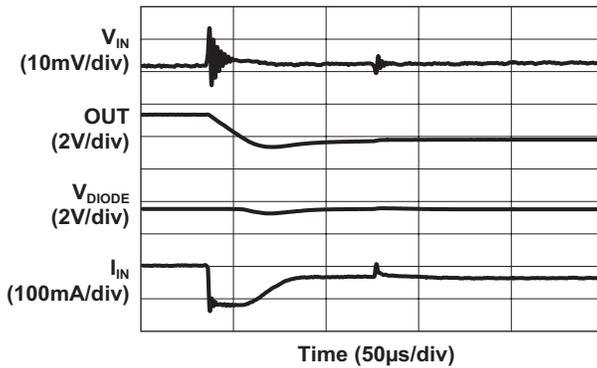
Load Switch to Charge Pump
(80mA)

V_{IN}
(20mV/div)

OUT
(1V/div)

V_{DIODE}
(1V/div)

I_{IN}
(200mV/div)

Time (50µs/div)

Turn-Off

ENSET
(1V/div)

V_{DIODE}
(2V/div)

I_{IN}
(100mA/div)

Time (200µs/div)
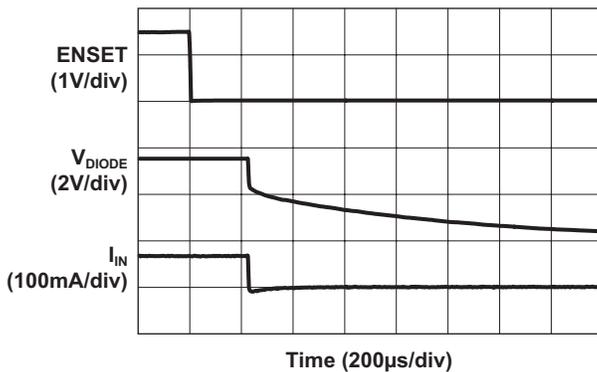
80mA Load Characteristics
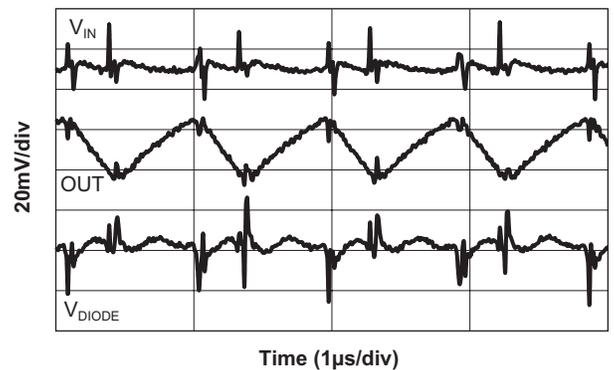
20mV/div

V_{IN}

OUT

V_{DIODE}

Time (1µs/div)

Functional Block Diagram
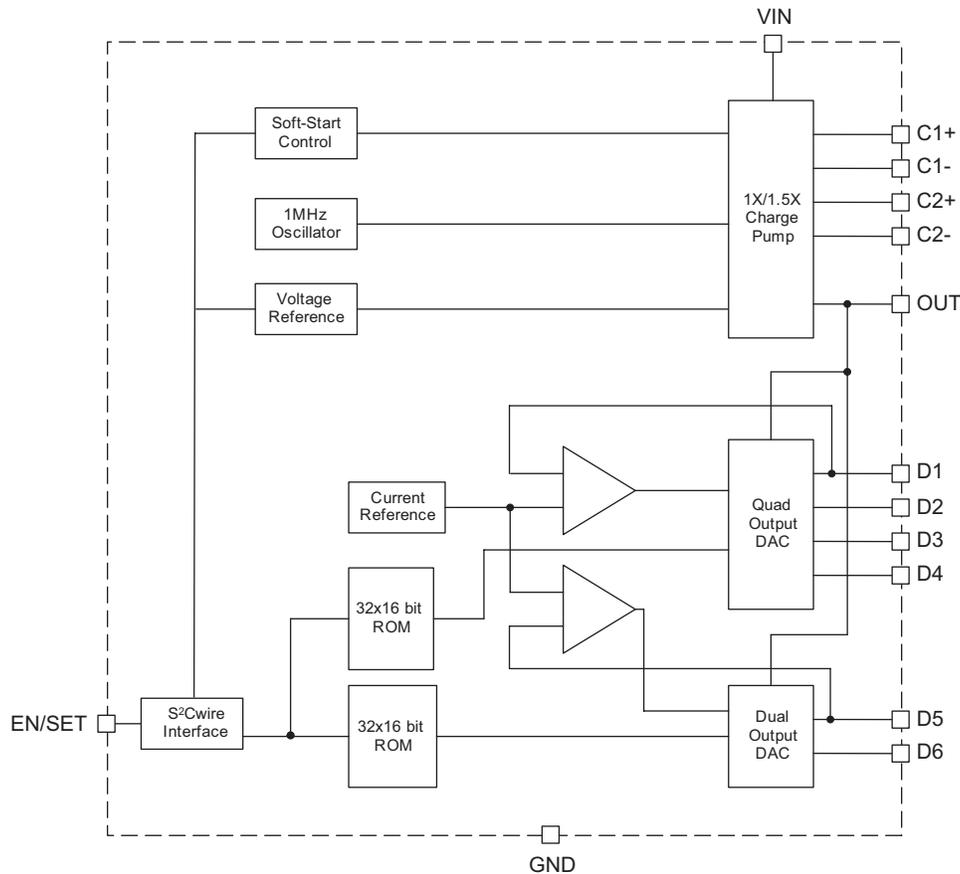
Functional Description

The AAT3134 is a dual mode load switch (1X) and high efficiency (1.5X) fractional charge pump device intended for white LED backlight applications. The fractional charge pump consists of a low dropout linear voltage regulator followed by a 1.5X charge pump with multiple current source outputs. To maximize power conversion efficiency, an internal feedback control sensing circuit monitors the voltage required on the constant current source outputs. This control circuit then sets the load switch and charge pump functions based upon the input voltage level versus the output voltage level needed. This function significantly enhances overall device efficiency when the input voltage level is greater than the voltage required at the constant current source outputs. The 1X load switch/1.5X charge pump mode decision is based on the voltage levels sensed on either the D1 or D5 output, whichever is greater. Switchover between the 1.5X (charge pump) operating mode and the 1X (load

switch) mode occurs automatically (as a function of input and output voltages) and does not require user intervention to maintain maximum efficiency.

The AAT3134 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 output capacitor (C_{OUT}). The LDO/1.5X charge pump output is converted into four (D1 to D4) constant current outputs to drive four individual LEDs with a maximum current of 20mA each and two (D5 and D6) constant current outputs with a maximum current of 20mA. The current source output magnitude is controlled by the EN/SET serial data interface. The interface records rising edges of the EN/SET pin and decodes them into 32 addresses corresponding to individual current level settings. The 32 addresses are divided up such that outputs D1 to D4 can be controlled independently of outputs D5 to D6. For Addresses 1 to 6, 7 to 12, 13 to 18, 19 to 24, and 25 to 30, outputs D1

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to D4 start at 0mA and increase from 1mA to 20mA in four steps. Outputs D5 and D6 remain constant over these address ranges which provides orthogonal control of the two channels. For Addresses 1 to 6, D5 and D6 are set to 0mA, Addresses 7 to 12 are 1mA; Addresses 13 to 18 are 10mA; Addresses 19 to 24 are 12mA; and Addresses 25 to 30 are 15mA. For maximum brightness control, Addresses 31 and 32 set D5 and D6 to the maximum 20mA level. For design flexibility, D1 to D4 are set to 0mA at Address 31, and 20mA at Address 32. This is summarized in Table 1 and Figure 1.

The modulo 32 interface wraps back to State 1 after the 32nd clock. With each EN/SET pulse, the output current changes to the next setting in the address decoding. To change settings to the previous address decoding, 31 EN/SET clock pulses are required. The counter can be clocked at speeds up to 1MHz, so that intermediate states are not visible. The first rising edge of EN/SET enables the IC and initially sets the output LED currents to 0mA. Additional clocks are required to set the desired current level. Once the final clock cycle is input for the desired brightness level, the EN/SET pin is held high to maintain the device output current at the programmed level. The device is disabled 500µs after the EN/SET pin transitions to a logic low state.

Applications Information

Constant Current Output Level Settings

The constant current source output amplitude for output D1 to D4 and D5 to D6 are set via the serial interface according to the scale described in Figure 1 and the previous section. Because the outputs D1 to D6 are true independent constant current sources, the voltage observed on any single given output will be determined by the actual forward voltage (V_F) for the LED being driven.

Since the output current of the AAT3134 is programmable through the S^2Cwire 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." Furthermore, with its high-speed serial interface (1MHz data rate), the output current of the AAT3134 can be changed successively to brighten or dim LEDs in smooth transitions (e.g., to fade out) or in abrupt steps, giving the user complete programmability and real-time control of LED brightness.
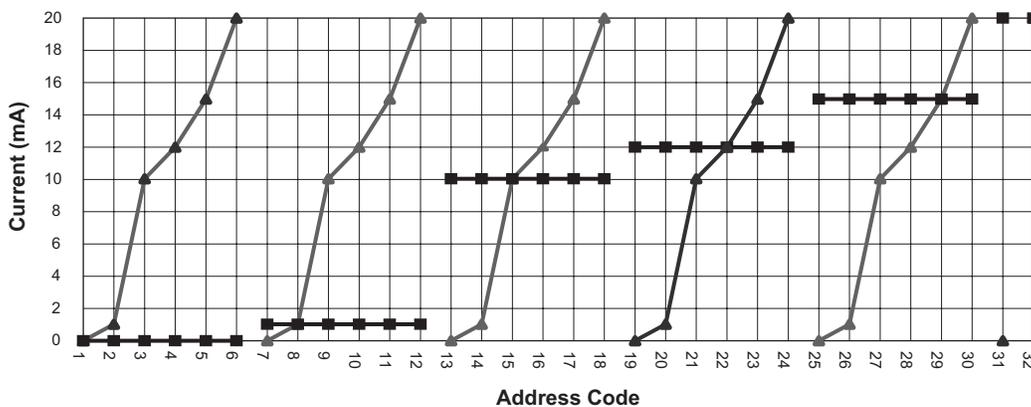

Figure 1: Output Current Level Settings.

AAT3134

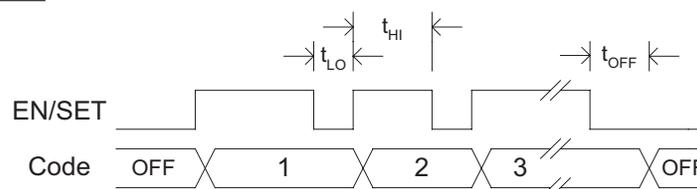## High Efficiency 1X/1.5X Fractional Charge Pump for White LED Applications

Address	Current Level Settings (mA)	
	D1 to D4	D5 to D6
1	0	0
2	1	0
3	10	0
4	12	0
5	15	0
6	20	0
7	0	1
8	1	1
9	10	1
10	12	1
11	15	1
12	20	1
13	0	10
14	1	10
15	10	10
16	12	10
17	15	10
18	20	10
19	0	12
20	1	12
21	10	12
22	12	12
23	15	12
24	20	12
25	0	15
26	1	15
27	10	15
28	12	15
29	15	15
30	20	15
31	0	20
32	20	20

Table 1: Constant Current Source Output Programming Levels.

EN/SET Serial Interface

The current source output magnitude is controlled by the EN/SET serial interface. The interface records rising edges of the EN/SET pin and decodes them into 32 individual current level settings, as summarized in Table 1. The modulo 32 interface wraps back to State 1 after the 32nd clock, so that the previous state is achieved by clocking the EN/SET pin 31 times. The counter can be clocked at speeds up to 1MHz, so that intermediate states are not visible. The first rising edge of EN/SET enables the IC and initially sets the output LED current to 0. Once the final clock cycle is input for the desired brightness level, the EN/SET pin is held high to maintain the device output current at the programmed level. The device is disabled 500µs after the EN/SET pin transitions to a logic low state. The EN/SET timing is designed to accommodate a wide range of data rates. After the first rising edge of EN/SET, the charge pump is enabled and reaches full capacity after the soft-start time (T_{SS}). During the soft-start time, multiple clock pulses may be entered on the EN/SET pin to set the final output current level with a single burst of clocks. Alternatively, the EN/SET clock pulses may be entered one at a time to gradually increase the LED brightness over any desired time period. A constant current is sourced as long as EN/SET remains in a logic high state. The current source outputs are switched off after EN/SET has remained in a low state for at least the T_{OFF} timeout period.

LED Selection

The AAT3134 is specifically intended for driving white LEDs. However, the device design will allow the AAT3134 to drive most types of LEDs with forward voltage specifications ranging from 2.0V to 4.3V. 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 output current sources 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 sources in the AAT3134 make it capable of driving LEDs with forward voltages as high as 4.3V at full current from an input supply as low as 3.0V. Outputs can be paralleled to drive high-current LEDs without complication.

EN/SET Timing Diagram

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Device Switching Noise Performance

The AAT3134 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 AAT3134 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 efficiency of the charge pump section itself. Due to the unique circuit architecture and design of the AAT3134, it is very difficult to measure efficiency in terms of a percent value comparing input power over output power.

Since the AAT3134 outputs are pure constant current sources and typically drive individual loads, it is difficult to measure the output voltage for a given output (D1 to D6) to derive an overall output power measurement. For any given application, white LED forward voltage levels can differ, yet the output 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 components count, reliability, operating range, and total energy usage...*not just % efficiency.*

The AAT3134 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 outputs D1 through D6 for a given constant current setting. Depending upon V_{IN} being greater than the specific voltage seen across the load on D1 (or D6), the device will operate in load switch mode. If V_{IN} is less than the voltage required on the constant current source, the device will operate in 1.5X charge pump mode. Each of these two modes will yield different efficiency values. One should refer to the following two sections for explanations for each operational mode.

Load Switch Mode Efficiency

The AAT3134 load switch mode is operational at all times and functions alone to enhance device power conversion efficiency when the condition exists where V_{IN} is greater than voltage across the load connected to the constant current source outputs. 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:

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

-or-

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

Charge Pump Section Efficiency

The AAT3134 contains a fractional charge pump which will boost the input supply voltage when V_{IN} is less than the voltage required on the constant current source outputs. 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 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:

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

-or-

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

For a charge pump with an output of 5V and a nominal input of 3.5V, the theoretical efficiency is 95%. Due to internal switching losses and IC quiescent current consumption, the actual efficiency can be measured at 93%. These figures are in close agreement for output load conditions from 1mA to 100mA. Efficiency will decrease as load current drops below 0.05mA or when the level of V_{IN} approaches V_{OUT}. Refer to the Typical Characteristics section of this document for measured plots of efficiency versus input voltage and output load current for the given charge pump output voltage options.

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 AAT3134. 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 have tight tolerance and are stable over temperature. Large capacitor values are typically composed of X7R, X5R, Z5U, or Y5V dielectric materials. Large ceramic capacitors, greater than 2.2μF, are often available in low-cost Y5V and Z5U dielectrics, but capacitors greater than 1μF are usually not required for AAT3134 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 AAT3134 has a thermal protection circuit that will shut down the internal LDO and charge pump if the die temperature rises above the thermal limit, as is the case during a short-circuit of the OUT pin.

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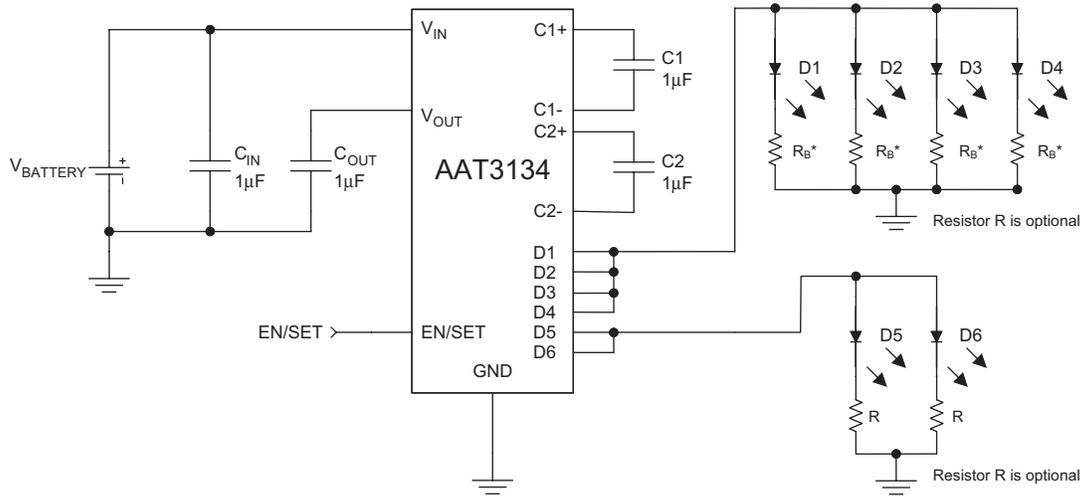
*In some applications, white LED forward voltages (V_F) can vary significantly. Ballast resistors between the LED cathodes and ground are recommended for balancing the forward voltage differences. The ballast resistor value may be approximated by the following equation:

$$R_B = \frac{V_{SOURCE} - V_F}{I_F}$$

**Figure 2: AAT3134 Driving Two Groups of Paralleled White LEDs
(e.g., main and sub-LCD backlights).**

AAT3134

High Efficiency 1X/1.5X Fractional Charge Pump for White LED Applications

Ordering Information

Package	Marking[1]	Part Number (Tape and Reel)[2]
QFN44-16	JBXYY	**AAT3134ISN-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

QFN44-16[3]
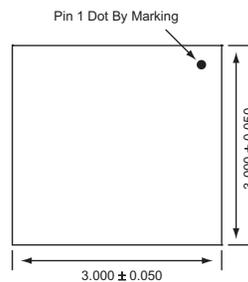
Top View
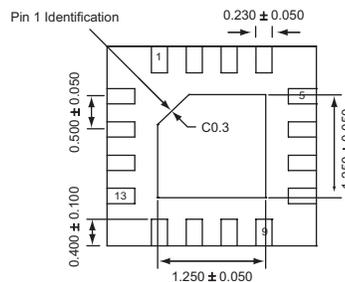
Bottom View
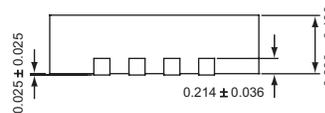
Side View

All dimensions in millimeters.

1. XYY = assembly and date code.
2. Sample stock is generally held on part numbers listed in **BOLD**.
3. The leadless package family, which includes QFN, TQFN, DFN, TDFN and STDFN, has exposed copper (unplated) at the end of the lead terminals due to the manufacturing process. A solder fillet at the exposed copper edge cannot be guaranteed and is not required to ensure a proper bottom solder connection.

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