AAT3123/4

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

ChargePump™

General Description

The AAT3123/24 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 to drive up to 6 LEDs from a 2.7V to 5.5V input. Outputs may be operated individually or paralleled for driving higher-current LEDs. Low external parts counts (two 1µF flying capacitors and two small 1µF capacitors at V_{IN}, and OUT) make the AAT3123/24 ideally suited for small battery-powered applications.

AnalogicTech™'s Simple Serial Control™ (S^2Cwire™) interface is used to enable, disable and set the LED drive current with a 32 level logarithmic scale LED brightness control. The AAT3123/24 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 AAT3123 is available in very small 12 pin TSOPJW package. The six output AAT3124 is available in a 16 pin 4x4mm QFN package.

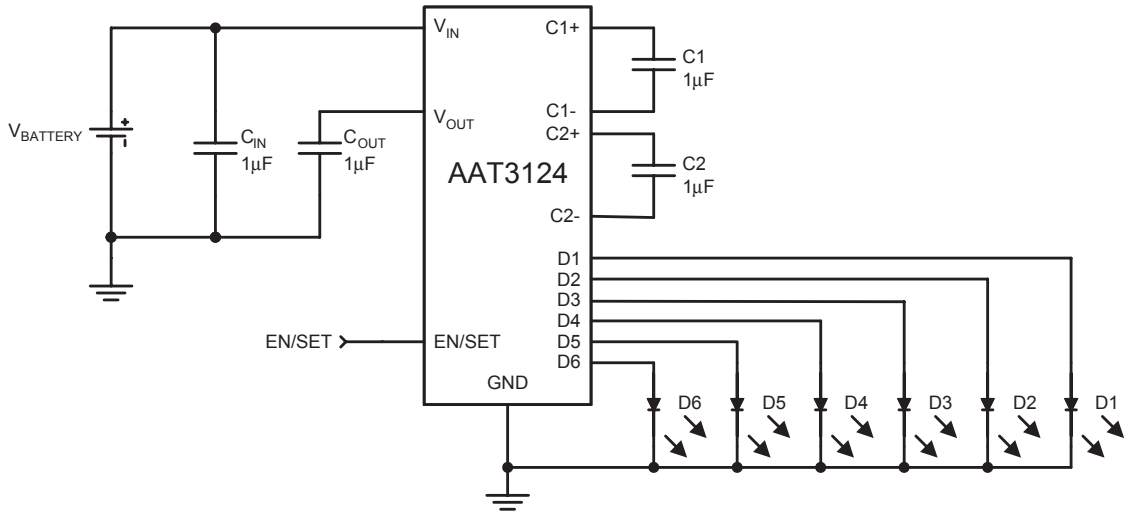
Features

- Dual Mode 1x and 1.5x Charge Pump for Maximum Efficiency
- Drives Low-V_F & High-V_F Type LEDs
- Up to 6 20mA Outputs
- 32 Position Logarithmic Scale with Digital Control
- Simple Serial Control™ (S^2Cwire™) interface
- Low Noise Constant Frequency Operation
- 1MHz Switching Frequency
- Small Application Circuit
- Regulated Output Current
- Automatic Soft-Start
- V_{IN} Range: 2.7V to 5.5V
- No Inductors
- Iq < 1µA in Shutdown
- Temperature Range -40 to 85°C.
- 16 pin 4x4 QFN package (AAT3124)
- 12 pin TSOPJW-12 package (AAT3123)

Applications

- White LED Backlighting
- White Photo-Flash for DSCs
- Color (RGB) Lighting
- Programmable Current Source

Typical Application

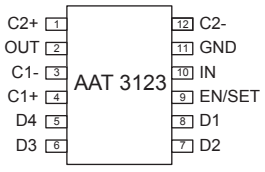


Pin Descriptions

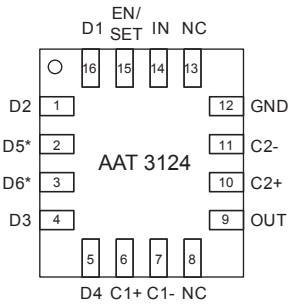
Pin #		Symbol	Function
AAT3123 (TSOPJW-12)	AAT3124 (16LD 4x4 QFN)		
8	16	D1	Current source output #1
7	1	D2	Current source output #2
6	4	D3	Current source output #3
5	5	D4	Current source output #4
	2	D5	Current source output #5
	3	D6	Current source output #6
4	6	C1+	Flying Capacitor 1 + terminal. Connect a 1µF capacitor between C1+ and C1-.
3	7	C1-	Flying Capacitor 1 - terminal
1	10	C2+	Flying Capacitor 2 + terminal. Connect a 1µF capacitor between C2+ and C2-.
12	11	C2-	Flying Capacitor 2 - terminal
11	12	GND	Ground
2	9	OUT	Charge pump output. Requires 1µF capacitor connected between this pin and ground.
10	14	IN	Input power supply. Requires 1µF capacitor connected between this pin and ground.
9	15	EN/SET	Control Pin using S²Cwire serial interface.
	8, 13	NC	No Connection

Pin Configuration

12-Lead TSOPJW
(Top View)



16 LD 4x4mm QFN
(Top View)



Absolute Maximum Ratings[1]

Symbol	Description	Value	Units
V_{IN}	Input Voltage	-0.3 to 6	V
V_{OUT}	Charge Pump Output	-0.3 to 6	V
FB,$V_{EN/SET}$	FB or EN/SET to GND Voltage	-0.3 to 6	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

Notes:
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.

Thermal Information

Symbol	Description	Value	Units
θ_{JA}	Thermal Resistance [3] (QFN-16 package)	50	°C/W
θ_{JA}	Thermal Resistance [3] (TSOPJW-12 package)	160	
P_D	Maximum Power Dissipation (QFN-16 package, T_A = 25°C) [3, 4]	2	W
P_D	Maximum Power Dissipation (TSOPJW-12 package, T_A = 25°C) [3, 5]	0.625	

Note 3: Mounted on an FR4 board.
Note 4: Derate 20mW/°C above 25°C.
Note 5: Derate 6.25mW/°C above 25°C.

Electrical Characteristics[1]

C_{IN} = C_{OUT} = C1 = C2 = 1.0µF; T_A = -40 to 85°C unless otherwise noted. Typical values are at T_A = 25°C, V_{IN} = 3.5V.

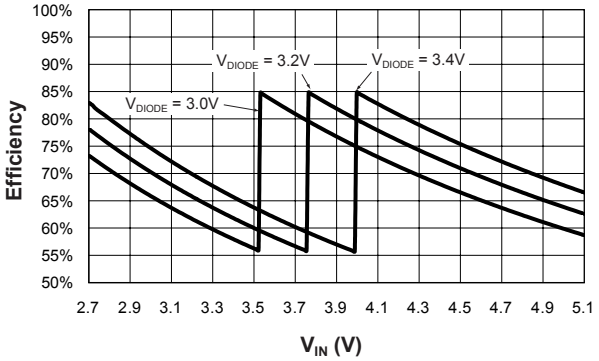
Symbol	Description	Conditions	Min	Typ	Max	Units
Input Power Supply						
V_{IN}	Operation Range		2.7		5.5	V
I_{cc}	Operating Current	3.0 ≤ V_{IN} ≤ 5.5, Active, No Load Current		1.8	3.5	mA
$I_{SHDN(MAX)}$	Shutdown Current	EN=0			1	µA
I_{DX}	Output Current	V_{IN} = 3.5V, Code = 32, T_A = 25°C	18	20	22	mA
$I_{(D\text{-}Match)}$	Current Matching between any two outputs	VD1:D4=3.6, V_{IN}=3.5V		0.5		%
		VD5:VD6=3.6, V_{IN}=3.5V		0.5		
η_{CP}	Charge Pump Section Efficiency	V_{IN} = 3.5V, $I_{OUT(TOTAL)}$ = 120mA, Measured from IN to OUT		93		%
Charge Pump Section						
T_{SS}	Soft start time			200		µs
F_{CLK}	Clock Frequency			1000		kHz
EN/SET						
$V_{EN(L)}$	Enable Threshold Low	V_{IN} = 2.7 to 5.5V			0.5	V
$V_{EN(H)}$	Enable Threshold High	V_{IN} = 2.7 to 5.5V	1.4			V
$T_{EN/SET\ LO}$	EN/SET low time		0.3		75	µs
$T_{EN/SET\ HI}$	Minumum EN/SET high time			50		ns
T_{OFF}	EN/SET Off Timeout				500	µs
Input Current	EN/SET input leakage		-1		1	µA

Note 1: The AAT3123/4 is guaranteed to meet performance specification over the -40°C to 85°C operating temperature range and are assured by design, characterization and correlation with statistical process controls.

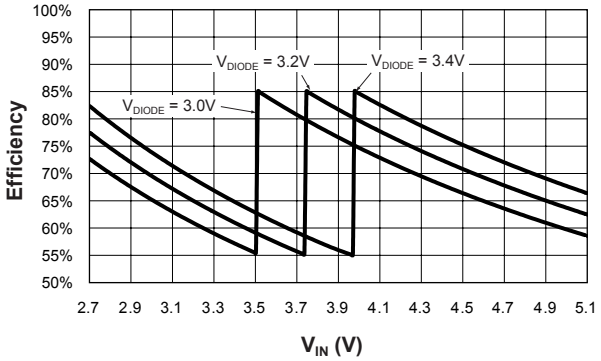
Typical Characteristics

(Unless otherwise noted, V_{IN} = 3.5V, C_{IN} = C_{OUT} = C1 = C2 = 1µF, T_A = 25°C)

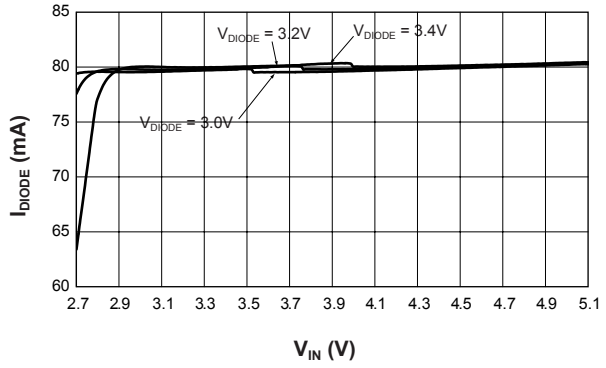
Efficiency vs. V_{IN} (4x20mA)



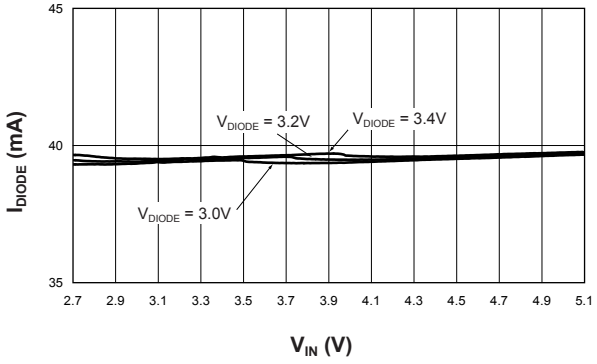
Efficiency vs. V_{IN} (4x10mA)



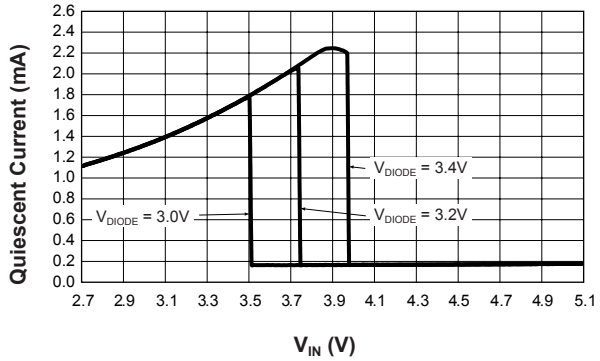
I_{DIODE} vs. V_{IN} (4x20mA)



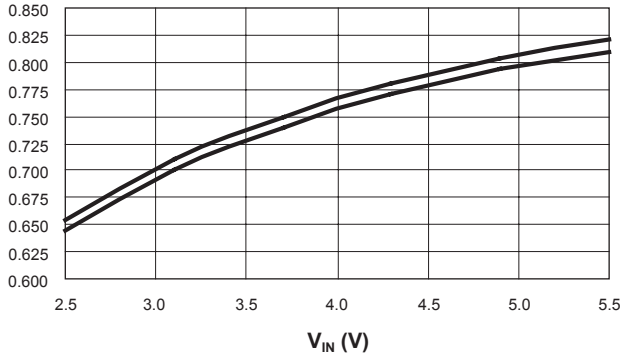
I_{DIODE} vs. V_{IN} (4x10mA)



Quiescent Current vs. V_{IN}



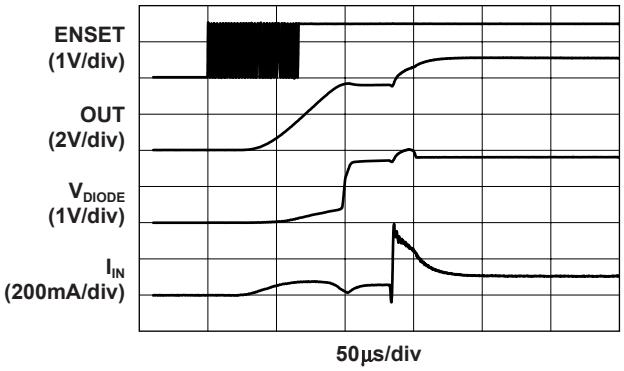
V_{IH} and V_{IL} vs. V_{IN}



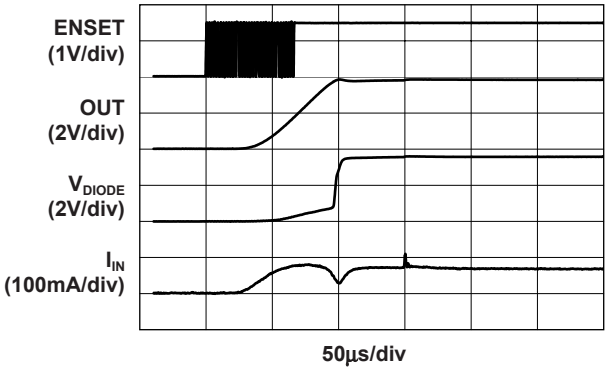
Typical Characteristics

(Unless otherwise noted, V_{IN} = 3.5V, C_{IN} = C_{OUT} = C1 = C2 = 1µF, T_A = 25°C)

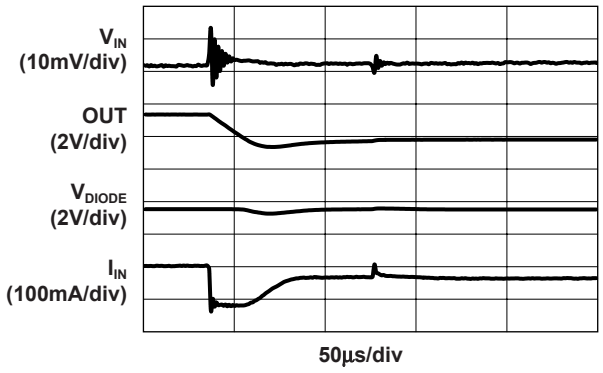
Turn-On to Full Scale Charge-Pump



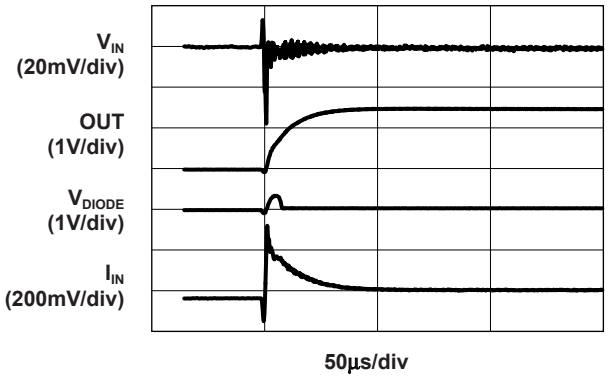
Turn-On to Full Scale Load-Switch



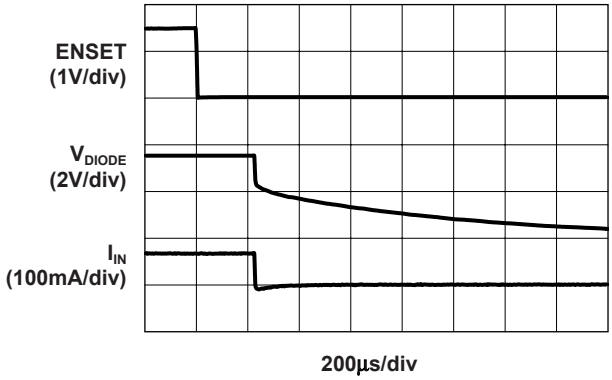
Charge Pump to Load Switch (80mA)



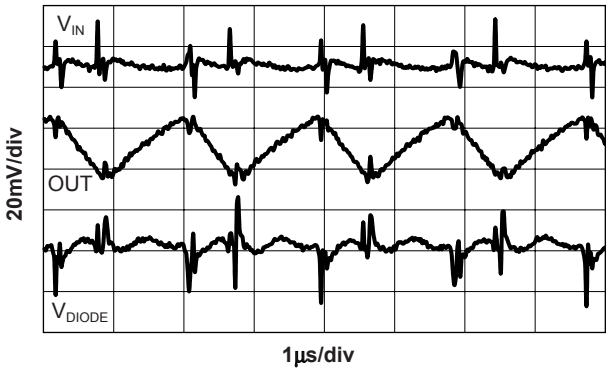
Load Switch to Charge Pump (80mA)



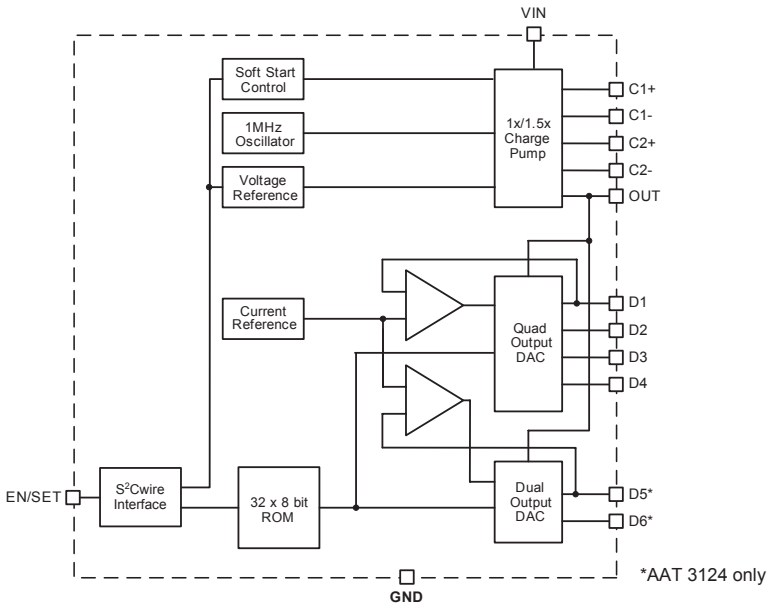
Turn-Off



80mA Load Characteristics



Functional Block Diagram



Functional Description

The AAT3123/24 is a dual mode Load Switch (1X) and high efficiency (1.5X) fractional charge pump device intended for white LED back light 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 over all device efficiency when the input voltage level is greater then the voltage required at the constant current source outputs. For the AAT3123, the 1X Load Switch / 1.5X charge pump mode is decided on the voltage sensed on the output D1. The AAT3124 bases the 1X Load Switch/1.5X charge pump mode decision is based on the voltage levels sensed on either the output D1-D4 output group or the D5-D6 output group, which ever 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 AAT3123/24 requires only four external components: two 1µF ceramic capacitors for the charge pump flying capacitors (C1 and C2), 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) or six (D1-D4 and D5-D6) constant current outputs to drive four or six individual LEDs with a maximum current of 20mA each. The current source output magnitude is controlled by the EN/SET serial data S²C interface. The interface records rising edges of the EN/SET pin, and decodes them into 32 individual current level settings each 1dB apart (see Current Level Settings below). Code 32 is full scale, and Code 1 is full scale attenuated by 31dB. The modulo 32 interface wraps states back to state 1 after the 32nd clock.

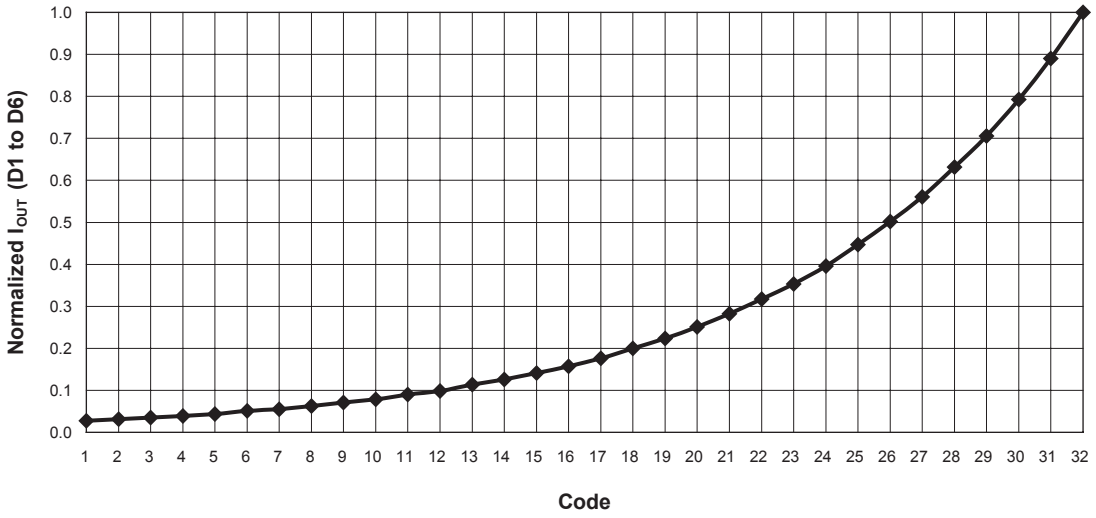
With each EN/SET pulse, the output current increases by 1dB. To decrease the output current by 1dB, 31 EN/SET clock pulses are required. The counter can be clocked at speeds up to 1MHz, so intermediate states are not visible. The first rising edge of EN/SET enables the IC and initially sets the output LED current to -31dB, the lowest setting equal to 525µA. 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 D6 are set via the serial interface according to a logarithmic scale where each code is 1dB greater than the previous code. In this manner, LED brightness appears linear with each increasing code count. 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.

Normalized Output Current Settings



Since the output current of the AAT3123/24 is programmable through its simple single-wire serial interface, no PWM (pulse width modulation) or additional control circuitry is 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 AAT3123/24 can 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.

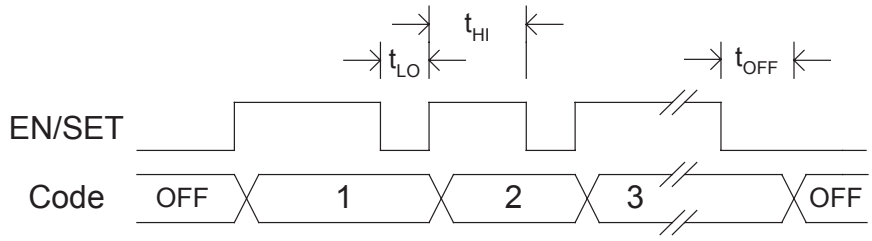
Constant Current Source Output Programming Levels (mA):

Code	I_{OUT} (mA)	Code	I_{OUT} (mA)
1	0.549	17	3.529
2	0.627	18	4.000
3	0.706	19	4.471
4	0.784	20	5.020
5	0.863	21	5.647
6	1.020	22	6.353
7	1.098	23	7.059
8	1.255	24	7.922
9	1.412	25	8.941
10	1.569	26	10.039
11	1.804	27	11.216
12	1.961	28	12.627
13	2.275	29	14.118
14	2.510	30	15.843
15	2.824	31	17.804
16	3.137	32	20.000

EN/SET Serial Interface

The current source output magnitude is controlled by the EN/SET pin, using AnalogicTech's Simple Serial Control (S²Cwire) interface. The interface records rising edges of the EN/SET pin, and decodes them into 32 individual current level settings each 1dB apart. Code 32 is full scale, and Code 1 is full scale attenuated by 31dB. The modulo 32 interface wraps states back to state 1 after the 32nd clock, so 1dB of attenuation is achieved by clocking the EN/SET pin 31 times. 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 -31dB, the lowest setting equal to 525µA. 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 (tSS). 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.

EN/SET Timing



LED Selection

The AAT3123/24 is specifically intended for driving white LED's. However, the device design will allow the AAT3123/24 to drive most types of LED's 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) LED's, 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 LED's. The *low-dropout* current-sources in the AAT3123/24 makes it capable of driving LED's 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 LED's without complication.

Device Switching Noise Performance

The AAT3123/24 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 AAT3123/24 soft-start feature prevents noise transient effects associated with in-rush currents during the start up of the charge pump circuit.

Power Efficiency and Device Evaluation

The charge pump efficiency discussion in the following sections only account for the efficiency of the charge pump section itself. Due to the unique circuit architecture and design of the AAT3123/24, it is very difficult to measure efficiency in terms of a percent value comparing input power over output power.

Since the AAT3123/24 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 component count, reliability, operating range and total energy usage...*Not just "% efficiency"*.

The AAT3123/24 efficiency may be quantified under very specific conditions and is dependant upon the input voltage versus the output voltage seen across the loads applied to outputs D1 through D4 or D6 for a given constant current setting. Depending upon the case of V_{IN} being greater than the specific voltage seen across the load on D1 (or D5 when the AAT3124 is used) the device will operate in "Load Switch" mode. If the voltage seen on the constant current source output is less than V_{IN} then 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 AAT3123/24 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 then 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:

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

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

$$\eta = P_{OUT}/P_{IN} = (V_{OUT} \times I_{OUT})/(V_{IN} \times I_{OUT}) = V_{OUT}/V_{IN}$$

or

$$\eta(\%) = 100(V_{OUT}/V_{IN})$$

Charge Pump Section Efficiency

The AAT3123/24 contains a fractional charge pump which will boost the input supply voltage in the event where V_{IN} is less then 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 a 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.

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

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:

$$\eta = P_{OUT}/P_{IN} = (V_{OUT} \times I_{OUT})/(V_{IN} \times 1.5I_{OUT}) = V_{OUT}/1.5V_{IN}$$

$$\eta(\%) = 100(V_{OUT}/1.5V_{IN})$$

For a charge pump with an output of 5 volts and a nominal input of 3.5 volts, 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 level of V_{IN} approaches V_{OUT}. Refer to the Typical Characteristics section 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}, C1, C2, C_{OUT} is important because they will affect turn on time, output ripple and transient performance. Optimum performance will be obtained when low ESR (<100mΩ) ceramic capacitors are used. In general, low ESR may be defined as less than 100mΩ. A capacitor 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 AAT3123/24. 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)

ESR is an important characteristic to consider when selecting a capacitor. ESR is a resistance internal to a capacitor, which 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 COG materials. NPO and COG materials typically 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, typically greater than 2.2 F are often available in low cost Y5V and Z5U dielectrics, but capacitors greater than 1µF are typically not required for AAT3123/24 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 AAT3123/24 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.

Driving Multiple LED's, White LED display module back lights and individual LED's connected in parallel

The AAT3123/24 D1 to D6 outputs are true constant current sources capable of driving up to 20mA each over the operation input voltage range. Since these outputs are true constant current sources, they may be connected in parallel to drive a single power output. Any combination of outputs (D1 to D6) may be connected in parallel. The maximum total output current is a sum of how many current sources are parallel connected. This feature is particularly useful to power pre-manufactured display modules which are pre-wired with white LED backlights connected in a parallel circuit configuration. Any combination of outputs may be connected in parallel to drive groups of LED's. The AAT3123 internal current source reference circuit bases feedback from current sensed on the D1 output. The AAT3124 internal current source reference circuit bases feedback from current sensed on the D1 and D5 outputs. For best operation, the only requirement for this type of application is the output D1 (and or D5 for the AAT3124) should always be connected to the load circuit.

The AAT3124 may be used to drive multiple LED's having differing forward voltages. Using feedback techniques, the current in D1 to D4 output currents sources are referenced to the current in the LED connected to D1. In AAT3124 (six output version), the D5 and D6 output current sources are referenced to the current in D5, not to D1. If all six LED's are of similar type, the diodes will be matched in current, maintaining uniform LED brightness despite variations in manufacturer, production, etc.

If however, the diodes are dramatically different in type comprising a mix of high-V_F type and low-V_F-type LED's, the AAT3124 has the capability to optimally drive up to four LED's of one-type and up to two LED's of another type simultaneously. Such a feature can be useful for driving different color LED's; driving both display backlight and photo-flash LED's; or for driving main-LCD and sub-LCD display LED backlights from a single Charge Pump IC. For example, when driving independent RGB LED's, the green and blue type LED's typically require a high V_F to operate (e.g. 3.7V) while the red LED needs a low forward voltage (e.g. 2V). By connecting the green and blue diodes to outputs D1 to D4 and the red diodes to D5 and D6, good control and uniformity in brightness is maintained despite the 2V difference in the diode forward voltages. The AAT3124 determines if the 1.5X charge pump circuit is needed based on the voltage on D1 and D5, which ever one is higher. If adequate voltage is available to drive the higher voltage LED (of output D1 or D5) without the charge pump running, the IC automatically switches into step down (1X) mode to maximize efficiency.

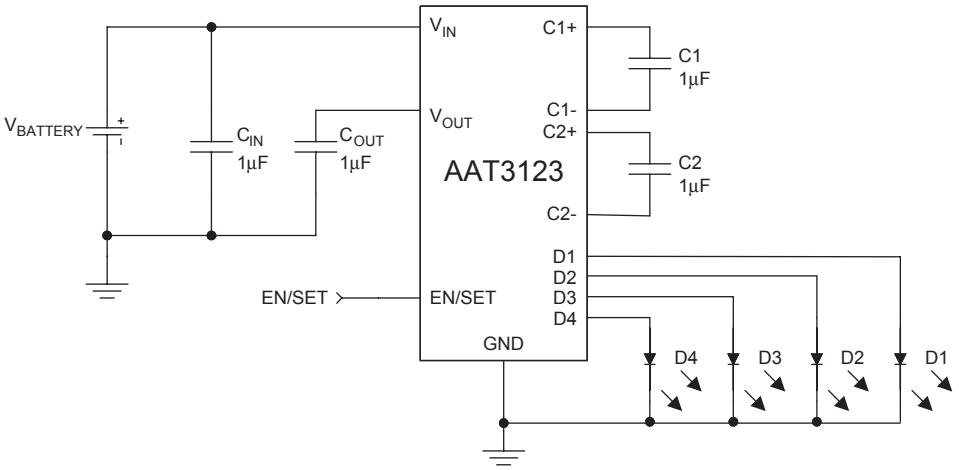
Similarly, if a 4V photo-flash LED-array is connected to outputs D1 through D4 (with the outputs shorted together) and two 3.3V sub-LCD-display backlight LED's are connected to outputs D5 and D6, then the AAT3124 can optimally drive each set of LED's at the programmed current level (see application schematics). The photo-flash can be disabled by an N-channel switch connected in series with the photo-flash LED.

The AAT3123/24 has only one programmed value of current and does not allow for separate on/off or brightness control of each current source output. This limitation can easily be circumvented by introducing grounded source N-channel MOSFET switches in series with the LEDs to turn any given LED (or bank of LEDs) on or off. The various LEDs can be turned on and off independently, simultaneously, or multiplexed to produce any variety of lighting effects. By reprogramming the current source (via the serial interface) between switching transitions, the brightness of individual LEDs, or banks of LEDs can also be controlled.

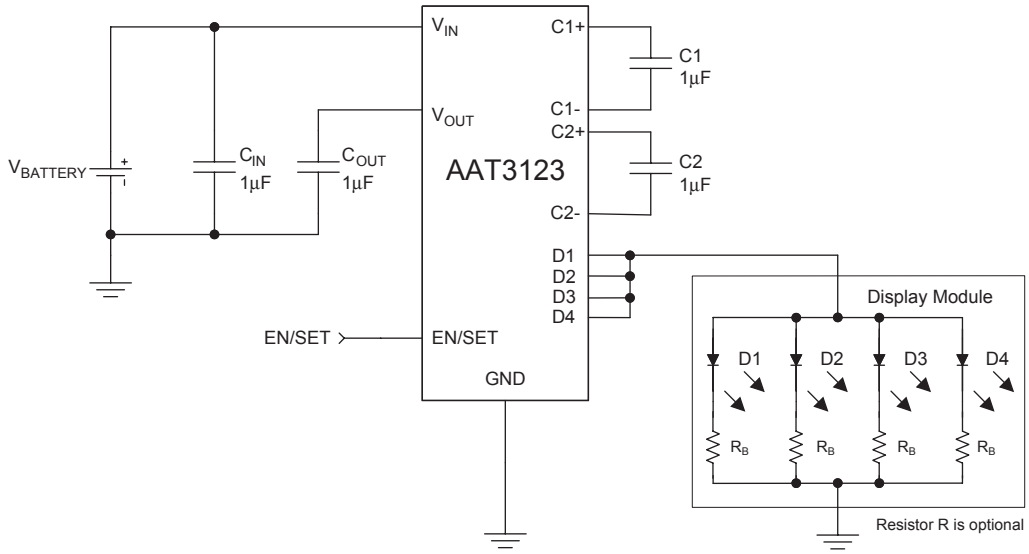
Charge Pump Compatibility

The 4-output AAT3123 is pin-compatible with the AAT3113 in both QFN and TSOPJW-12 packages. The six-output AAT3124 is pin compatible with the AAT3114 in the QFN package. Compared to the AAT3113/14, the AAT3123/24 offers an improved overall efficiency, wider operating range, and the ability to drive high-V_F type LED's (up to 4.3V) at full current from a 3V input condition. The AAT3123/24 is well suited for battery powered applications using single-cell lithium-ion (Li-Ion) batteries (4.2V to 2.8V), lithium polymer batteries, and 3-series connected dry cells (3.6V).

Additional Application Circuits

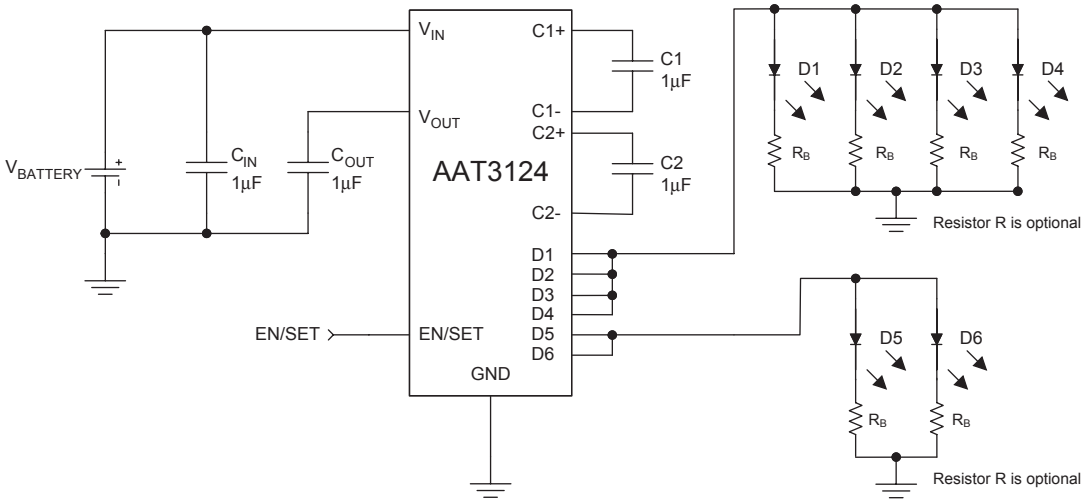


Typical AAT3123 Application Circuit

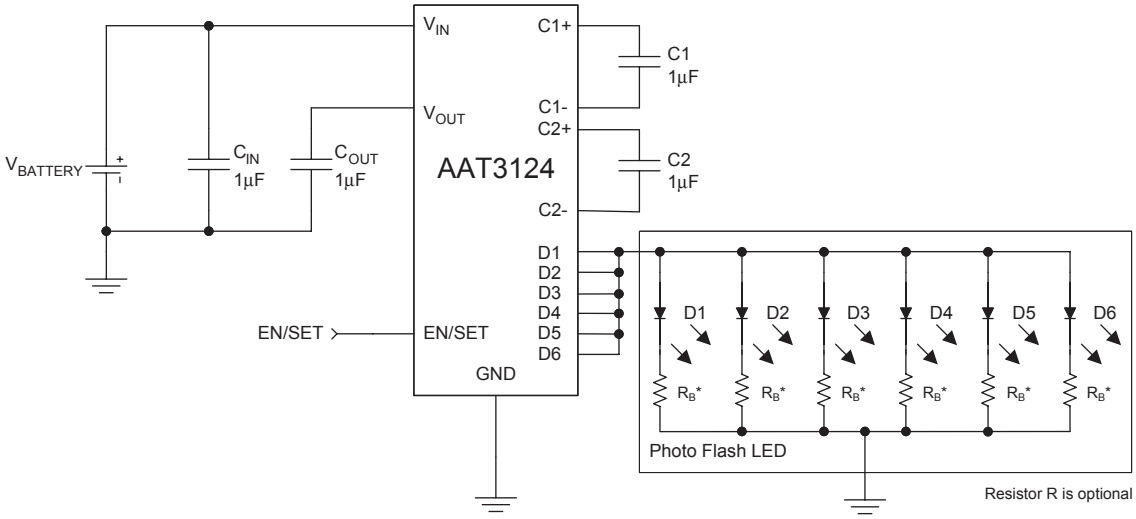


AAT3123 Driving a Display Module with 4 Paralleled White LED's

Additional Application Circuits



AAT3124 Driving Two Groups of Paralleled White LED's (e.g. main-LCD & sub-LCD backlights)

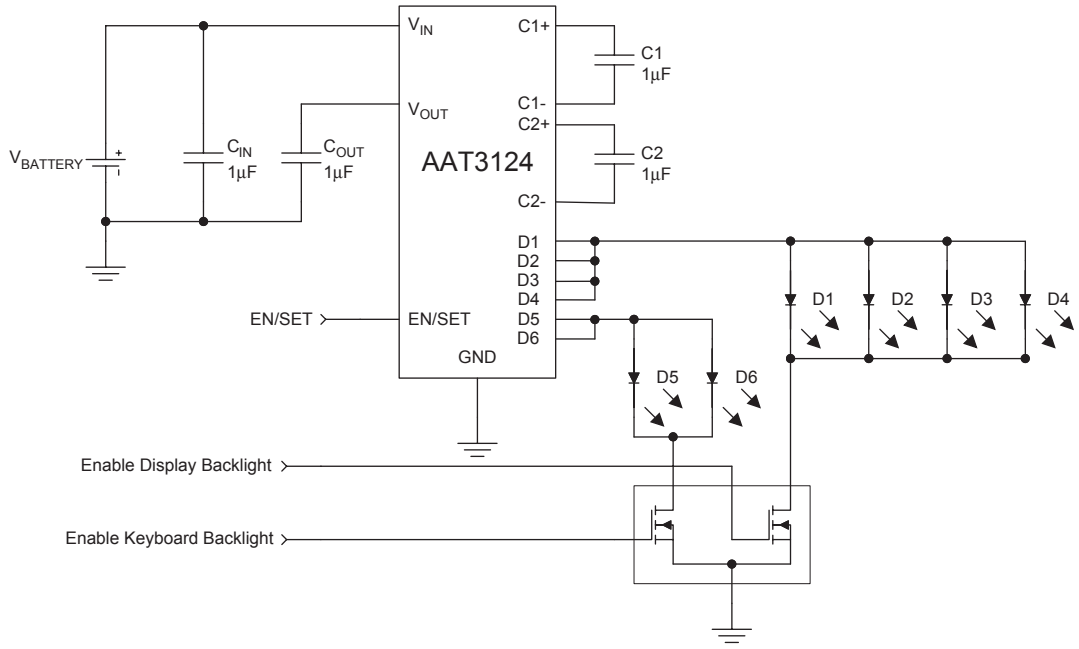


*In some applications, white LED forward voltages (V_F) can vary significantly. Ballast resistors between the LED cathodes and ground are recommended for balancing the forward voltage differences. The ballast resistor value may be approximated by the following equation:

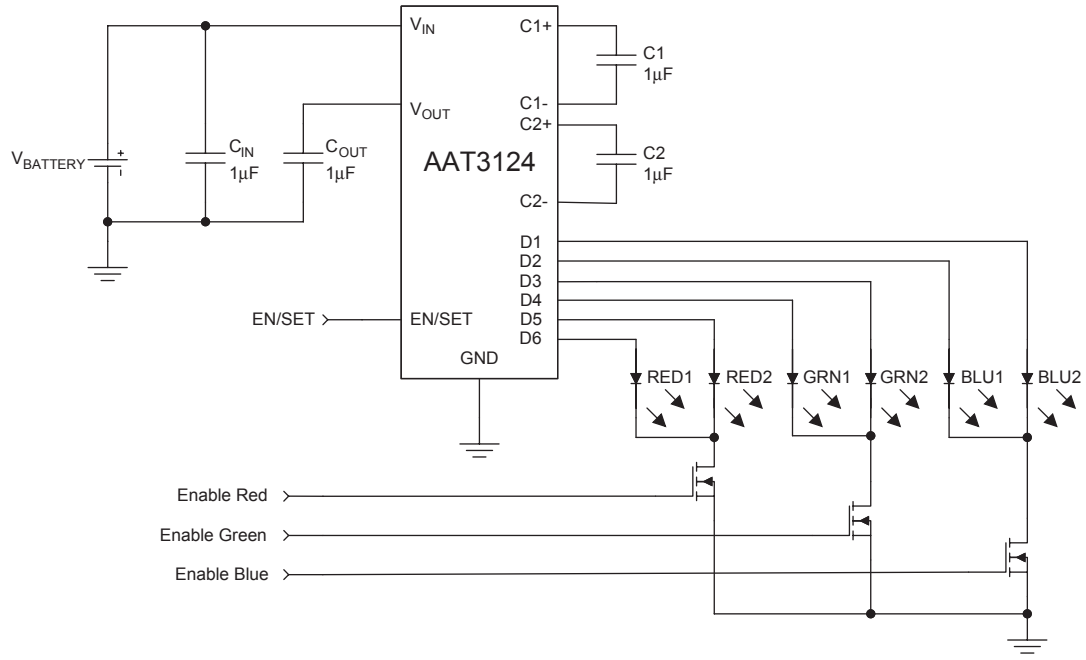
$$R_B = \frac{V_{SOURCE} - V_F}{I_F}$$

AAT3124 Driving High Current Photo-Flash LED

Additional Application Circuits

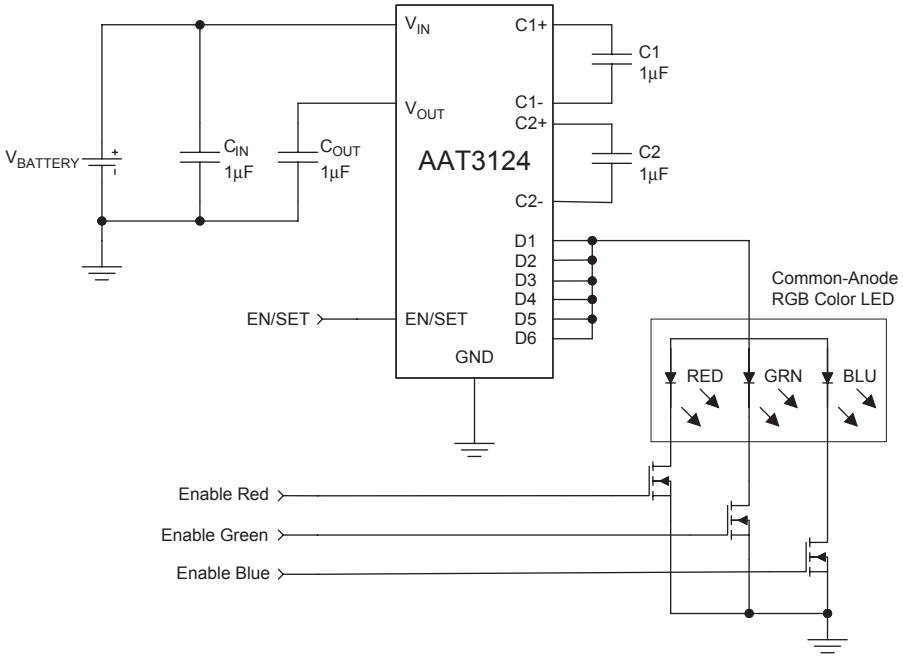


AAT3124 Driving Two Groups of Paralleled White LEDs (with Series N-channel Switch)



AAT3124 Separately Driving RGB Color LEDs

Additional Application Circuits



AAT3124 Driving Common-Anode RGB Color LED

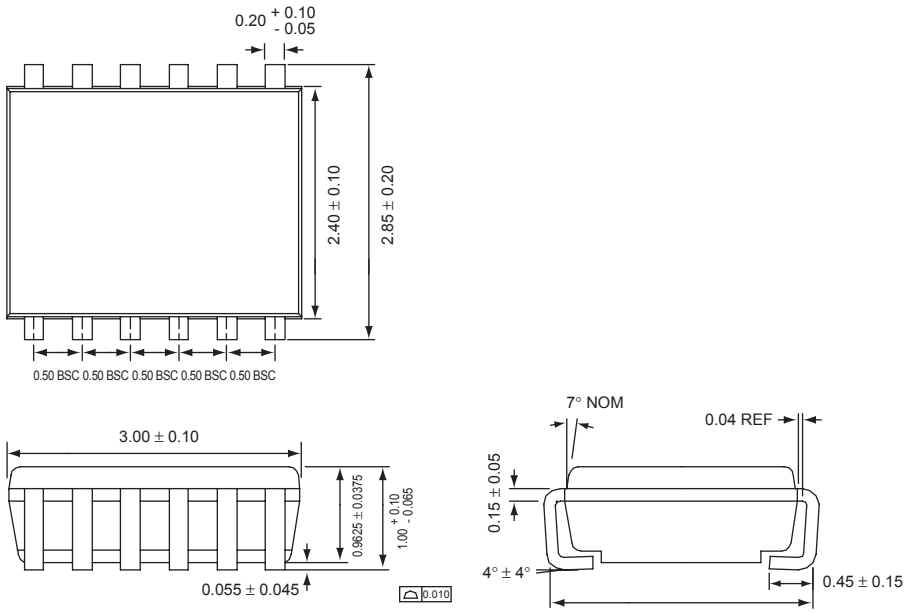
Ordering Information

Package	Marking[1]	Part Number (Tape and Reel)
TSOPJW-12	IRXYY	**AAT3123ITP-20-T1**
QFN44-16	ISXYY	**AAT3124ISN-20-T1**

Note: Sample stock is generally held on all part numbers listed in **BOLD**.
Note 1: XYY = assembly and date code.

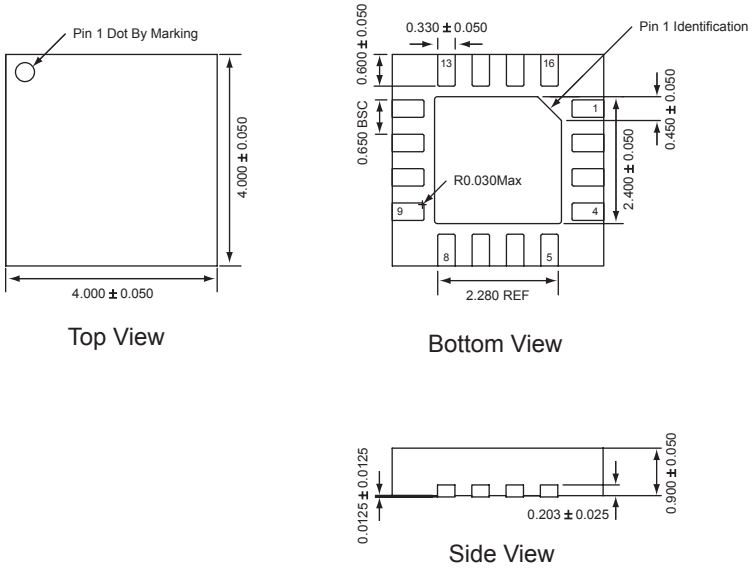
Package Information

TSOPJW-12



All dimensions in millimeters.

QFN44-16



All dimensions in millimeters.

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