SGM3124
White LED Charge Pump Current Source with PWM Brightness Control

GENERAL DESCRIPTION

The SGM3124 is a charge pump with PWM brightness control for white LED supplies in LCD display backlight applications. The supply voltage ranges from 2.7V to 5.5V, it is ideally suited for all applications powered by a single Li-Ion battery cell or three to four NiCd, NiMH, or alkaline battery cells.

The device provides a constant current for each LED, and the initial current value can be set by an external resistor. High efficiency is achieved by utilizing a 1×/1.5× fractional conversion technique in combination with very low dropout current sources.

The SGM3124 is capable of driving up to three channels of LEDs at 30mA per channel from a 2.7V to 5.5V input. Additionally, the current controlled charge pump ensures low input current ripple and EMI. A low external part count (two 0.47μF flying capacitors and two small 1μF capacitors at VIN and VOUT) makes this part ideally suited for small, battery-powered applications.

The SGM3124 is available in a Green, space-saving TQFN-3×3-16L package, and is rated over the -40℃ to +85℃ temperature range.

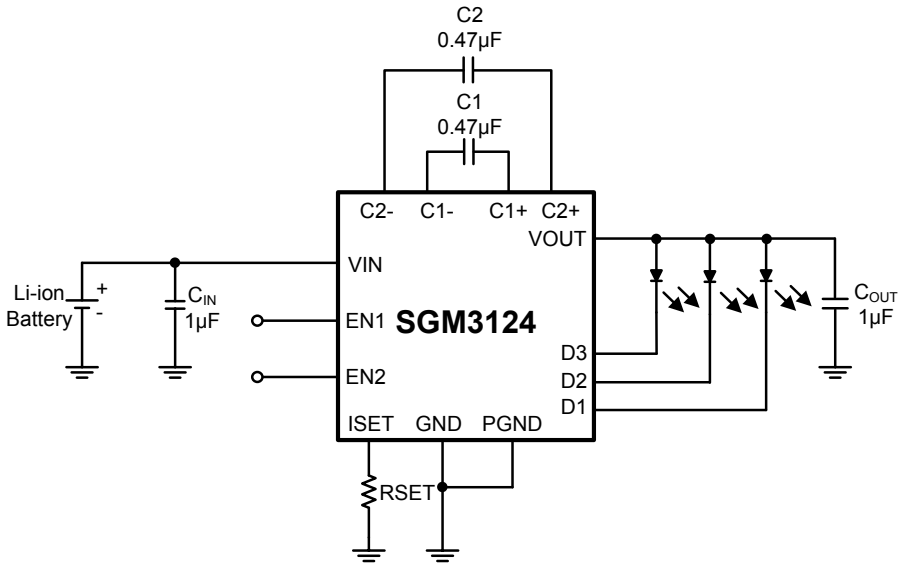
FEATURES

- **Input Voltage Range: 2.7V to 5.5V**
- **Drives up to 3 LEDs at 30mA Each**
- **LED Brightness Control Through PWM Control Signal**
- **High Efficiency by Fractional Conversion with 1× and 1.5× Modes**
- **Switching Frequency: 1MHz**
- **Regulated Output Current with 0.5% Matching**
- **Internal Soft-Start Limits Inrush Current**
- **Low Input Ripple and Low EMI**
- **Over-Current and Over-Temperature Protected**
- **Under-Voltage Lockout with Hysteresis**
- **Available in Green TQFN-3×3-16L Package**

APPLICATIONS

Cellular Phones
Smart Phones
Digital Cameras
Handheld PCs
Camcorders
PDAs
Keypad Backlight

TYPICAL APPLICATION



PACKAGE/ORDERING INFORMATION

MODEL	PACKAGE DESCRIPTION	SPECIFIED TEMPERATURE RANGE	ORDERING NUMBER	PACKAGE MARKING	PACKING OPTION
SGM3124	TQFN-3×3-16L	-40℃ to +85℃	SGM3124YTQ16G/TR	3124TQ XXXXX	Tape and Reel, 3000

NOTE: XXXXX = Date Code and Vendor Code.

Green (RoHS & HSF): SG Micro Corp defines "Green" to mean Pb-Free (RoHS compatible) and free of halogen substances. If you have additional comments or questions, please contact your SGMICRO representative directly.

ABSOLUTE MAXIMUM RATINGS

Supply Voltage Range ..... -0.3V to 6V
Voltage at EN1, EN2, VOUT, ISET ..... -0.3V to V_{IN}
Output Current at VOUT 300mA
Storage Temperature Range ..... -65℃ to +150℃
Maximum Junction Temperature ..... +160℃
Operating Temperature Range ..... -40℃ to +85℃
Lead Temperature (Soldering 10 sec) ..... +260℃
ESD Susceptibility
HBM 4000V
MM 400V

OVERSTRESS CAUTION

Stresses beyond those listed may cause permanent damage to the device. Functional operation of the device at these or any other conditions beyond those indicated in the operational section of the specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect reliability.

ESD SENSITIVITY CAUTION

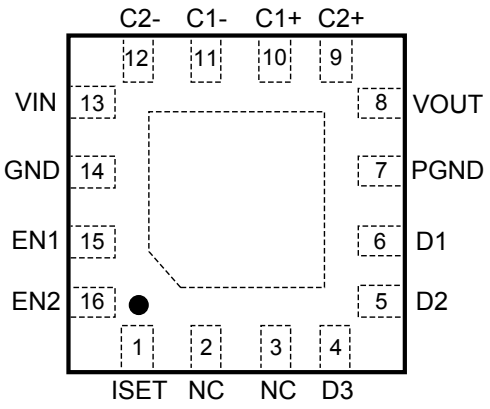
This integrated circuit can be damaged by ESD if you don't pay attention to ESD protection. SGMICRO recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage. ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

DISCLAIMER

SG Micro Corp reserves the right to make any change in circuit design, specification or other related things if necessary without notice at any time.

PIN CONFIGURATION

(TOP VIEW)



TQFN-3×3-16L

PIN DESCRIPTION

PIN	NAME	I/O	FUNCTION
1	ISET	I	Connect a resistor between this pin and GND to set the maximum current through the LEDs.
2, 3	NC	-	No Internal Connection.
4 - 6	D1 - D3	I	Current Sink Input. Connect the cathode of the white LEDs to these inputs.
7	PGND	-	Power Ground.
8	VOUT	O	Connect the Output Capacitor and the Anode of the LEDs to This Pin.
9	C2+	-	Connect to the Flying Capacitor C2.
10	C1+	-	Connect to the Flying Capacitor C1.
11	C1-	-	Connect to the Flying Capacitor C1.
12	C2-	-	Connect to the Flying Capacitor C2.
13	VIN	I	Supply Voltage Input.
14	GND	-	Analog Ground.
15	EN1	I	Enable Input. A logic high enables the converter, logic low forces the device into shutdown mode reducing the supply current to less than 1μA if EN2 is tied to GND.
16	EN2	I	An applied PWM signal reduces the LED current as a function of the duty cycle of the PWM signal. EN1 and EN2 can be tied together for PWM dimming between 0mA and the maximum set with ISET. EN1 and EN2 can also be used for digital dimming with 4 steps from 0mA to the maximum current set with ISET.
-	Power PAD		Connect with PGND and GND.

ELECTRICAL CHARACTERISTICS

(V_{IN} = 3.6V, EN1 = EN2 = V_{IN}, T_A = +25℃, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
SUPPLY VOULTAGE AND CURRENT						
Input Voltage Range	V_{IN}	I_{LED} = 25mA	2.7		5.5	V
Quiescent Power Supply Current	I_Q	V_{IN} = 4.2V, 1× mode, EN1 = EN2 = 1, I_{SET} = 0μA		100		μA
		V_{IN} = 4.2V, 1× mode, EN1 = EN2 = 1, I_{SET} = 20μA		200		μA
		I_{OUT} = 0mA, 1.5× mode		2		mA
Shutdown Supply Current	I_{SD}	EN1 = EN2 = GND		0.1	1	μA
CHARGE PUMP STAGE						
Over-Voltage Limit	V_{OUT}	LED1 unconnected, V_{IN} = 4.2V		5.3		V
Start-Up Time		C_{OUT} = 1μF, $I_{DX} \geq 0.9 \times I_{DX_SET}$		150		μs
Soft-Start Duration				130		μs
Switching Frequency	f		0.6	1	1.4	MHz
Efficiency	η	V_{IN} = 3.7V, I_{LED} = 15mA each, V_{DX} = 3.1V		83		%
Shutdown Temperature		Temperature rising		160		℃
Shutdown Temperature Hysteresis				20		℃
Input Current Limit		EN1 = EN2 = 1, I_{SET} = 100μA		300		mA
CURRENT SINKS						
Recommended Maximum Current per Current Sink	I_{DX}	3.2V ≤ V_{IN} ≤ 5.5V		30		mA
Current into Each Current Sink when ISET is Shorted to GND	I_{DX}	3V ≤ V_{IN} ≤ 5.5V, ISET shorted to GND		45		mA
Current Matching between Any Two Outputs		V_{DX} = 3.1V, T_A = +25℃	-3	0.5	3	%
Line Regulation		3V < V_{IN} < 5.5V, V_{LED} = 3.1V, EN1 = EN2 = 1, I_{SET} = 80μA		0.8		%
Reference Voltage for Current Set	V_{ISET}	EN2 = 0, EN1 = 1		200		mV
		EN2 = 1, EN1 = 0		400		
		EN2 = 1, EN1 = 1	580	600	620	
Recommended ISET Pin Current Range	I_{SET}		2		130	μA
I_{DX} to ISET Current Ratio	K	EN1 = EN2 = 1, I_{SET} = 80μA	230	255	280	
Voltage at D_X to GND	V_{SOURCE}	EN2 = 0, EN1 = 1		200		mV
		EN2 = 1, EN1 = 0		300		
		EN2 = 1, EN1 = 1		400		
EN1, EN2						
EN1, EN2 High Level Input Voltage	V_{IH}		1.3			V
EN1, EN2 Low Level Input Voltage	V_{IL}				0.3	V
EN1, EN2 Trip Point Hysteresis				75		mV
EN2 Input Leakage Current	I_{IKG}	EN1, EN2 = GND or EN1, EN2 = V_{IN} = 5.5V		0.1	1	μA
EN1 Input Leakage Current	I_{IKG}	EN1, EN2 = GND or EN1, EN2 = V_{IN} = 5.5V		0.1	1	μA
Under-Voltage Lockout Threshold	$V_{(UVLO)}$	Input voltage falling		2.1		V
Under-Voltage Lockout Hysteresis				20		mV
Frequency Range at PWM			0		50	kHz
Recommended ON-Time for PWM Signal				2.5		μs
Shutdown Delay Time				0.85		ms

TYPICAL PERFORMANCE CHARACTERISTICS

Table of Graphs

FIGURE		
1	Efficiency (η)	vs. Input Voltage (I_{LED} = 25mA, 20mA, 15mA, 10mA, 5mA per LED), EN2 = EN1 = 1. The curve with higher efficiency is for Input voltage from high to low.
2	LED Current, I_{LED}	vs. Duty Cycle on PWM (I_{LED_MAX} set to 20mA) For f = 32kHz, and f = 1kHz, DC = 1% to 100%, V_{IN} = 3.6V.
3	Switching Frequency (f)	vs. Operating Temperature (T_A = -40℃ to +85℃, V_{IN} = 3.6V)
4	Quiescent Current (I_Q)	vs. Input Voltage (T_A = +25℃) (measured with I_{D1} = 5mA)
5	LED Current Regulation	vs. Input Voltage 3 × 20mA
6	Maximum Output Current from Charge Pump Stage	vs. Input Voltage (T_A = +25℃)
7, 8	Dimming Response	PWM Signal and Current at D1 vs. Time-On Scope f = 32kHz and f = 1kHz, V_{IN} = 3.6V, duty cycle = 50%, EN1 = EN2 = PWM
9, 10	Start-Up Timing	V_{IN} = 3.6V, 3 × 20mA, EN1 = EN2 = 00 changed to EN2 = EN1 = 11
11	Input and Output Ripple	V_{IN} = 3.6V, 3 × 20mA, EN1 = EN2 = 1
12	Line Transient Response	V_{IN} and ID1 vs. Time-On Scope, LED current at D1 with V_{IN} = 4.2V to 3.6V to 4.2V with EN2 = EN1 = 11, 3 × 20mA

TYPICAL PERFORMANCE CHARACTERISTICS (continued)

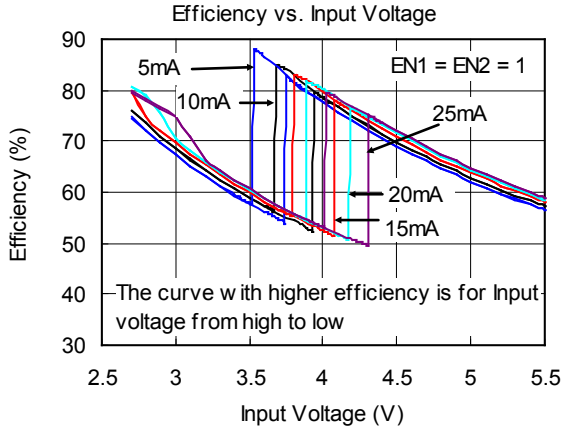


Figure 1

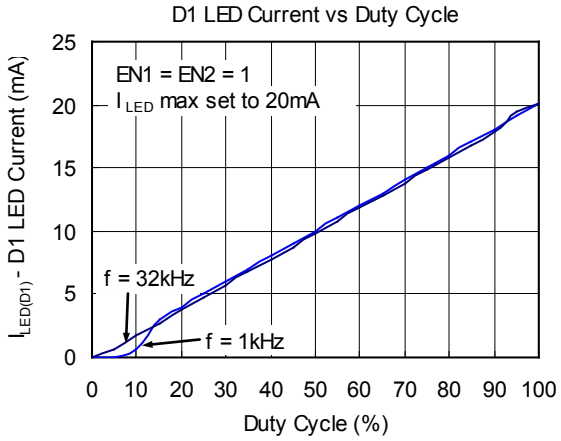


Figure 2

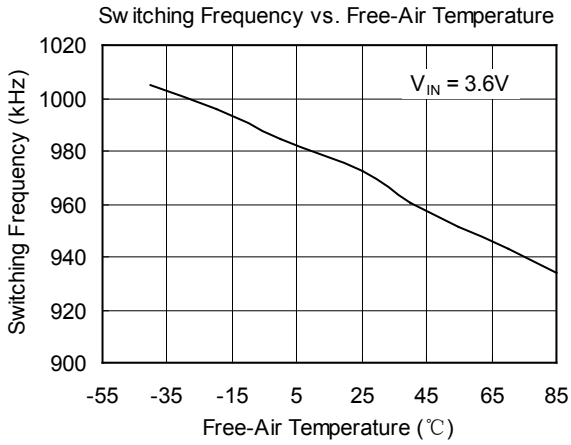


Figure 3

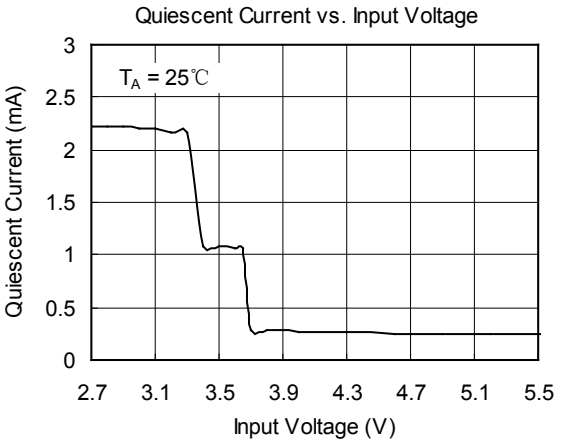


Figure 4

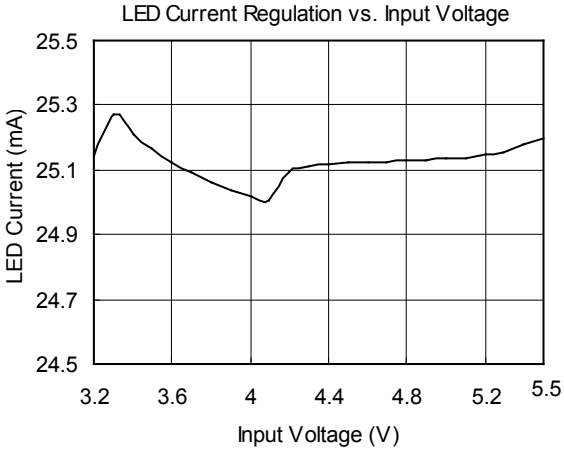


Figure 5

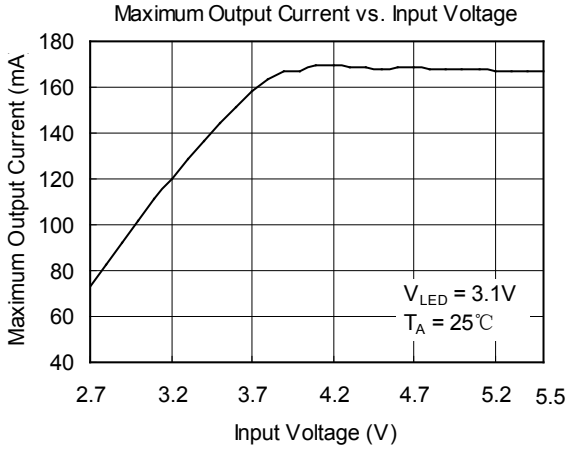


Figure 6

TYPICAL PERFORMANCE CHARACTERISTICS (continued)

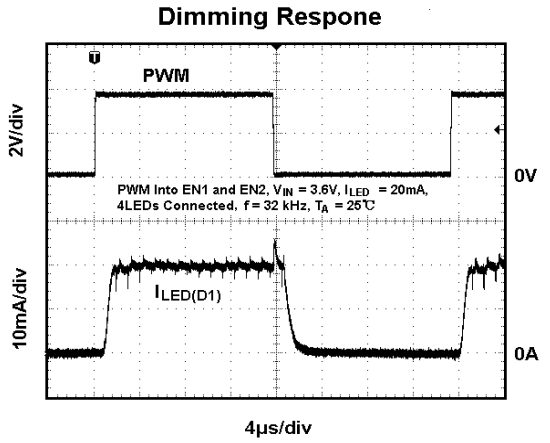


Figure 7

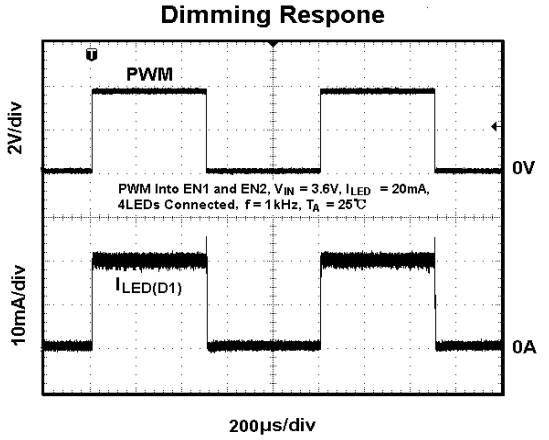


Figure 8

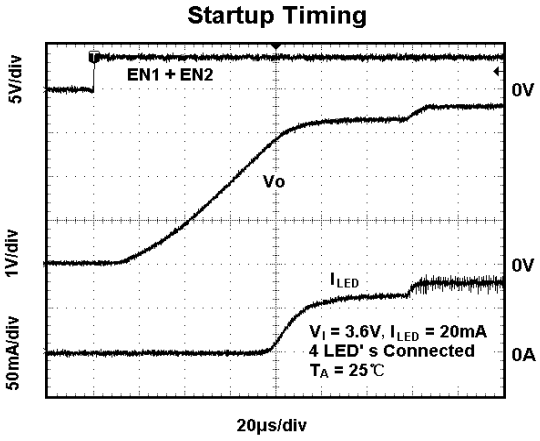


Figure 9

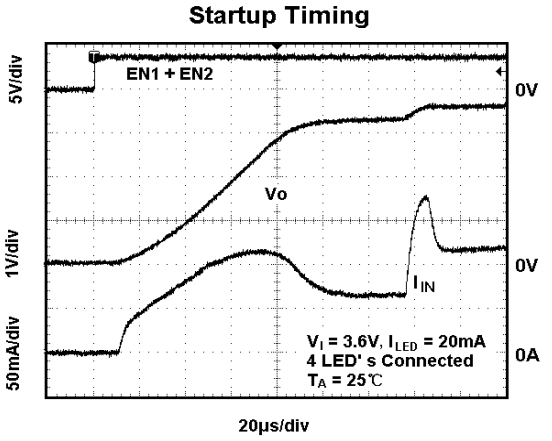


Figure 10

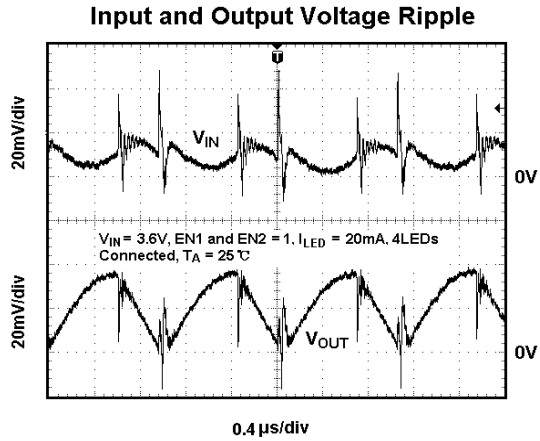


Figure 11

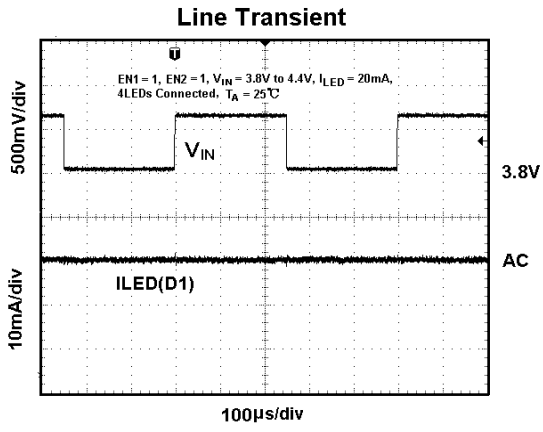
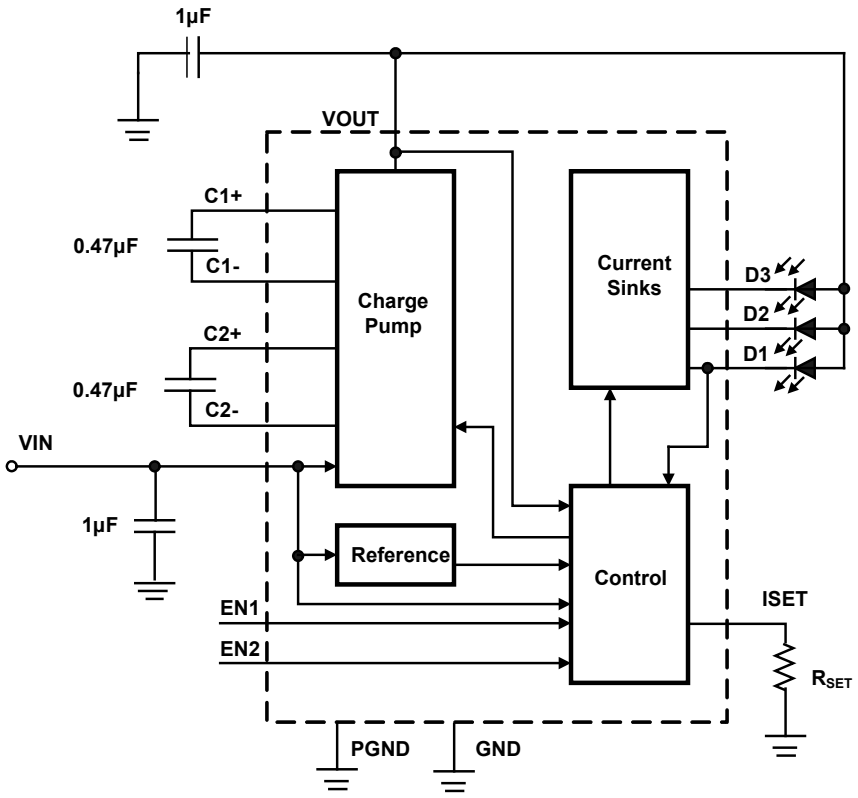


Figure 12

FUNCTIONAL BLOCK DIAGRAM



DETAILED DESCRIPTION

Operation

The SGM3124 uses a fractional conversion charge pump to generate a supply voltage for the integrated current sinks. These current sinks are used to ensure a constant current for each LED. Depending on the input voltage and programmed LED current, the charge pump either operates in the 1× mode or in the 1.5× mode. By switching automatically between these two modes, the circuit optimizes power conversion efficiency as well as extends operating time by allowing the discharge of the battery completely.

The charge pump can generate 90mA of output current, so each of the 3 LED outputs can be powered with up to 30mA of current. The maximum LED current is set by a resistor connected to the ISET pin. This resistor programs a reference current, which is current mirrored to set the LED current.

Applying a PWM signals to the EN1 pin and/or the EN2 pin controls the LED brightness. See a detailed description in the section Analog Dimming Using ISET Pin.

LED Current Adjustment (ISET)

A resistor programs a reference current, which is current mirrored to set the LED current. The voltage at the ISET pin depends on the status of EN1 and EN2. The current in each LED is typically 255 times the current through the resistor at ISET (see Table 2).

$$R_{ISET} = \frac{V_{ISET}}{I_{LED}} \times K$$

V_{ISET} — Voltage from ISET pin (0.2V, 0.4V or 0.6V) to GND (see Table 1)

I_{LED} — Current per LED from D_X pin to GND

K — D_X to ISET current ratio (typically 255)

The LED current varies linearly from 0mA to I_{LED} (MAX) by applying a PMW signal with 0% to 100% duty cycle. The LED brightness can however also be controlled by an analog control signal that is fed into the ISET pin.

DETAILED DESCRIPTION (continued)

Table 1. Enable Levels

ENABLE LEVEL		V_{ISET}	LED CURRENT
EN2	EN1		
0	0	0	0
0	1	200mV	1/3
1	0	400mV	2/3
1	1	600mV	Full

Table 2. R_{ISET} Values

SET DRIVE CURRENT (Full)	R_{ISET} COMPUTATION VALUE (kΩ)	STANDARD RESISTOR VALUE (kΩ)
30mA	5.1	5.1
25mA	6.12	6.19
20mA	7.65	7.68
10mA	15.3	15.4
5mA	30.6	30.9

Enable (EN1, EN2)

The enable pins EN1 and EN2 are used to enable the device or set it into shutdown. The SGM3124 is enabled if one of the enable pins is pulled higher than the enable trip point of 1.3V. The device starts up by going through the soft-start routine as described in the section Soft-Start. Pulling both pins to GND, after a delay, programs the device to shutdown. In shutdown, the charge pump, current sources, voltage reference, oscillator, and all other functions are turned off and the supply current is reduced to 0.1μA.

EN1 and EN2 can also be used for dimming. The logic levels at EN1 and EN2 set the minimum voltage at the current mirrors and the voltage at the ISET pin to GND. This sets the current at the LEDs to be either the full current or a fraction of the full current. See Table 1 for further details. The maximum current through the LEDs is set by a resistor connected between ISET and GND.

EN1 and EN2 can also be used for PWM dimming. The PWM signal can either be applied to EN1 or EN2, or both inputs can be tied together and the PWM signal can be applied to both pins. Depending on the configuration, the current during PWM dimming is switched between 0mA and its maximum (EN1 and EN2 connected to the PWM signal) or between 0mA and 1/3 of the full LED current if EN2 = 0 and EN1 is toggled. When EN1 = 0 and EN2 is toggled, the output current can be changed between 0mA and 2/3 of the full range.

Soft-Start

The SGM3124 has an internal soft-start circuit to limit the inrush current during start-up. This prevents possible voltage drops of the input voltage if a high impedance power source is connected to the input of the SGM3124. When the device starts up with an output voltage that is below the input voltage, the output capacitor is charged directly from the input with a current source. The output current increases linearly until the output reaches within 300mV of the input voltage. When the programmed output current can be reached with the 1× mode, the SGM3124 terminates the soft-start and begins normal operation. When the desired output current cannot be reached, the charge pump begins operation in 1.5× mode and pumps the output voltage up to the needed level to reach the programmed output current.

Under-Voltage Lockout

The under-voltage lockout circuit shuts down the device when the voltage at VIN drops below a typical threshold of 2.15V. This prevents damage to the device. The UVLO circuit allows the device to start up again after the voltage on the VIN pin has increased by about 50mV above the UVLO lockout threshold.

Short-Circuit and Over-Temperature Protection

The current at the VOUT pin is limited typically to 300mA. When the junction temperature exceeds +160℃, the device shuts down to protect the device from damage. After the temperature decreases to about +140℃, the device starts up again if it is enabled.

Over-Voltage Protection at VOUT

The device uses the voltage at D1 to regulate voltage at VOUT. In case D1 is not connected, an over-voltage protection circuit ensures that the output voltage at VOUT does not exceed its limits. The connection of the LEDs must be started using D1 first. For all other LEDs there is no restriction in the sequence. For example, if there are only 2 LEDs used, the first LED is connected to D1 and the other LED can be connected to any other of the D2 to D3 pins.

THEORY OF OPERATION/DESIGN PROCEDURE

Capacitor Selection

Ceramic capacitors such as X5R or X7R are recommended to be used with the SGM3124. For the two flying capacitors C1 and C2, it is important to use low ESR capacitors to avoid unnecessary efficiency losses. Low ESR capacitors on VOUT reduce the ripple voltage on the supply of the current sources. Table 3 lists capacitor types that have been tested with the SGM3124.

Table 3. Capacitors

PART	VALUE	VOLTAGE	MANUFACTURER	SIZE	WEBSITE
C1608X5R1A105M	1μF	10V	TDK	0603	www.componnent.tdk.com
C1608X5R1A474M	0.47μF	10V		0603	
C2012X7R1C105M	1μF	16V		0805	
LMK107BJ105MA	1μF	10V	Taiyo Yuden	0603	www.t-yuden.com
LMK107BJ474MA	0.47μF	10V		0603	
LMK212BJ105MG	1μF	10V		0805	

Power Dissipation

The maximum power dissipation inside the SGM3124 can be calculated based on the following equation:

$$P_{D_MAX} = [(1.5\times V_{IN}) - V_O + 0.4V] \times I_O$$

The maximum power dissipation occurs when the input voltage is just low enough to operate in 1.5× mode, with a forward voltage of the white LED at maximum. This is typically for V_{IN} = 4.2V and a forward voltage of 3.6V.

This needs to be lower than the maximum allowed power dissipation of the package, which can be calculated using the following equation:

$$P_{D_MAX,\ package} = \frac{T_{Jmax} - T_A}{R_{\theta JA}}$$

For example, the worst case power dissipation occurs at the input voltage level where the charge pump switches from the 1× mode to the 1.5× mode. At this operating point, the supply voltage to the current sources is at its maximum and the current sources must drop the most voltage in order to maintain a regulated output current.

The worst case power dissipation occurs when all 3 LED outputs are fully loaded with 30mA of LED current.

- With: V_{IN} = 4.2V, V_f = 3.6V, I_O = 75mA (1.5× mode)
- P_{D_MAX} = 0.203W

Power Efficiency

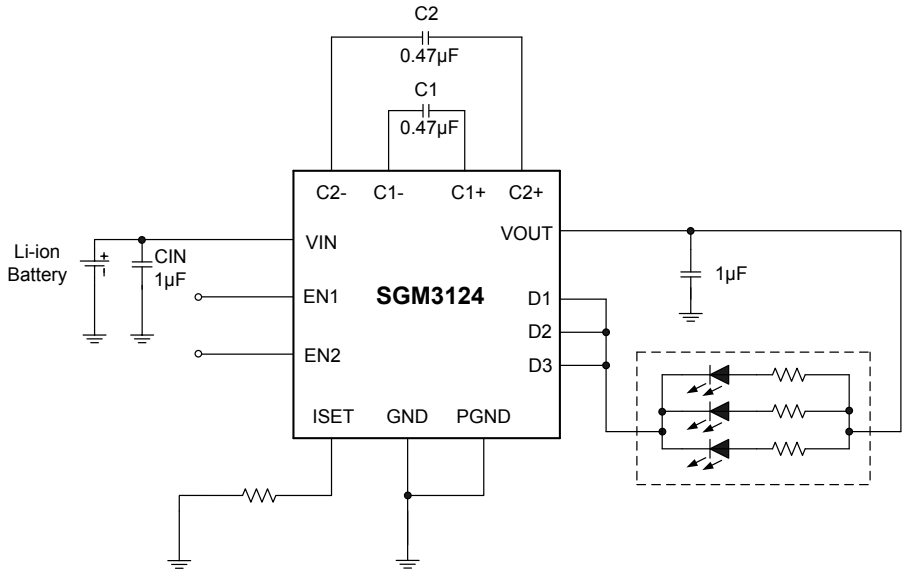
The power conversion efficiency of the SGM3124 can be calculated by adding up the products of each LED current and voltage and dividing it by the product of the input voltage and current. With a fully charged battery where the input voltage is typically above the LED forward voltage, the charge pump operates in the 1× mode and efficiency is very high. As the battery discharges, there is a point where the current sources no longer have enough voltage overhead to maintain a constant current regulation.

At that point, the charge pump switches into the 1.5× mode. The conversion efficiency is lowest at the crossover. As the battery discharges further, the efficiency again increases until at about 3.2V where it reaches a second maximum. Below 3.2V input voltage, the maximum current per LED is less than 30mA.

APPLICATION INFORMATION

Typical Application of a Smart Phone Display with Resistors Connected In Parallel

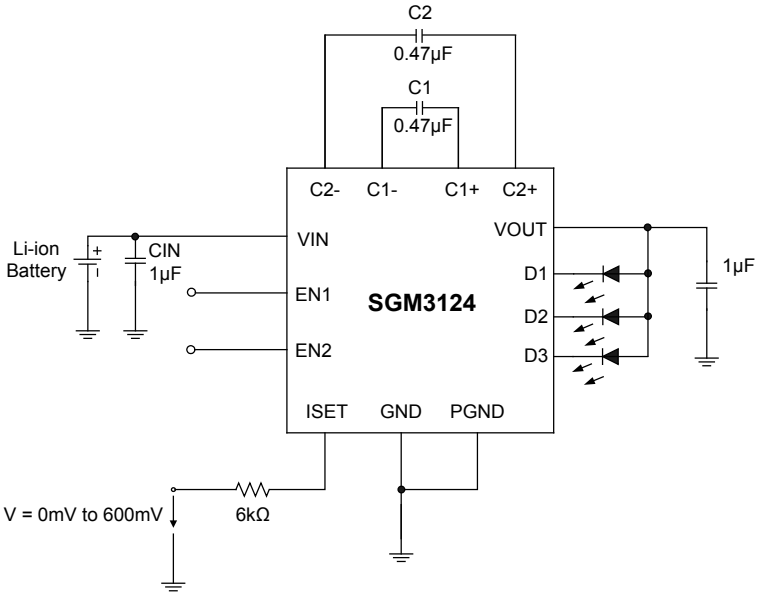
If more than 30mA of output current is needed, then the input pins to the current sinks can be connected in parallel as shown in the following application figure. This method can also be used to connect a LC display with only two connections for the white LEDs.



Analog Dimming Using ISET Pin

The ISET pin can be used to connect an analog dc signal in the range of 0mV to 600mV (EN1 = EN2 = 1) for analog dimming of the white LEDs. For an input voltage of 0V at ISET, the current is at its maximum, whereas at 600mV, the LED current is zero. The maximum current is:

- For EN2 = EN1 = 1: $I_{LED} = V_{SET}/R_{SET} \times K = 0.6V/6000 \times 255 = 25.5mA$ per LED.
- For EN2 =1, EN1 = 0: $I_{LED} = V_{SET}/R_{SET} \times K = 0.4V/6000 \times 255 = 17mA$ per LED.
- For EN2 = 0, EN1 = 1: $I_{LED} = V_{SET}/R_{SET} \times K = 0.2V/6000 \times 255 = 8.5mA$ per LED.
- With EN2, EN1 set to 10 or 01, a voltage of 400mV or 200mV is required to set the LED current to zero.



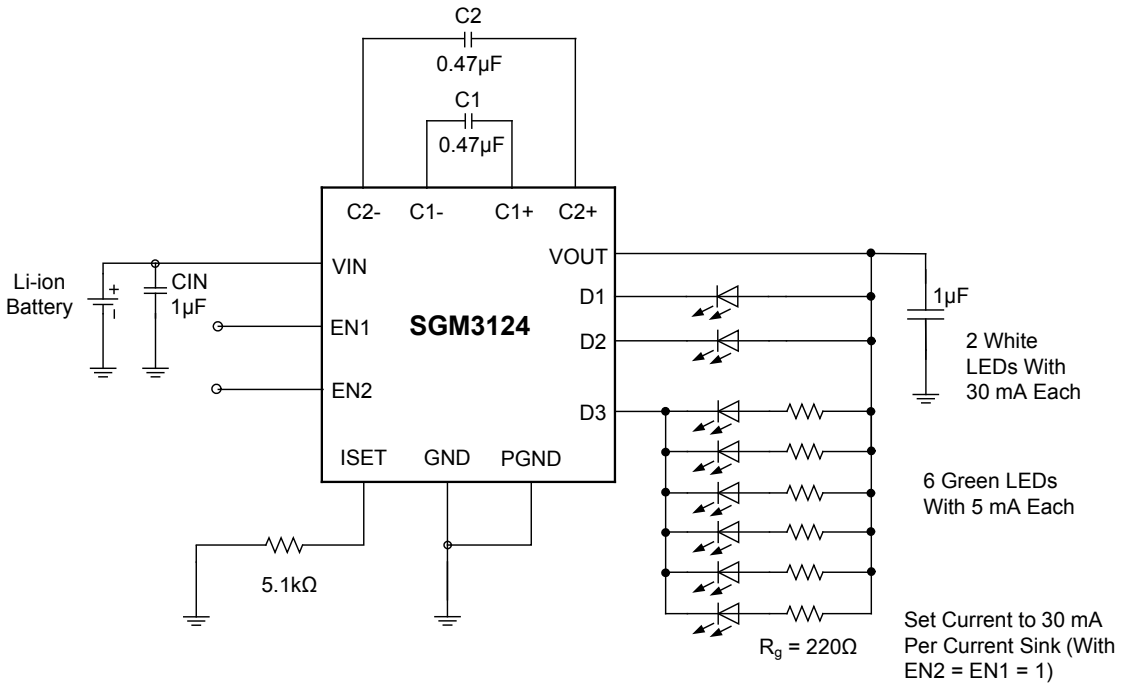
APPLICATION INFORMATION (continued)

Typical Application Using 2 White LEDs and 6 Green LEDs for LCD Backlight and Keyboard Lighting

The SGM3124 can be used to power any kind of LED. It is also possible to mix white LEDs with color LEDs which have a lower forward voltage. The LED with the highest forward voltage (typically the white LED) has to be connected to D1, because the output voltage of the charge pump is regulated in such a way to keep the voltage drop from D1 to GND at 400mV (with EN1 = EN2 = 1). Therefore the output voltage of the charge pump is regulated to:

$V_{OUT} = V_{D1} + V_{FLEDD1}$
V_{OUT} — Output voltage at VOUT
V_{D1} — Voltage from D1 to GND (V_{SOURCE} at D1 pin, see electrical characteristics)
V_{FLEDD1} — Forward voltage of the LED connected to D1

Resistor R_g is used to provide current sharing between the 6 green LEDs. The upper value is calculated using:

$$R_g = \frac{V_{FLEDD1} - V_{Fg}}{I_g}$$

V_{Fg} — Forward voltage of a green LED
I_g — Current per green LED