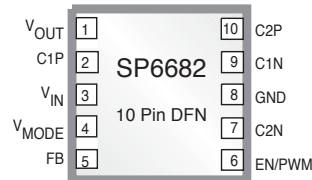# SP6682

High Efficiency Charge Pump Regulator for White LEDs

FEATURES

- ■ Ideal For White LED Driver
- ■ Low Profile, Inductorless Regulator
- ■ Output Current up to 200mA
- ■ X1.5 and X2 Modes for Highest Efficiency
- ■ +2.7V to +5.5V Input Voltage Range
- ■ Fast Turn-On Time, 175μS
- ■ 1mA Quiescent Current
- ■ <1.5μA Shutdown Current
- ■ 600kHz Oscillator
- ■ Programmable Output Current or Voltage
- ■ PWM Dimming Control with Enable Pin
- ■ Shutdown to Disconnect Output from Input
- ■ Soft Start to Eliminate In-Rush Current
- ■ Industry Standard 10-pin MSOP Package and Small 10-pin DFN Package

V_{OUT}	1	10	C2P
C1P	2	9	C1N
V_{IN}	3	8	GND
V_{MODE}	4	7	C2N
FB	5	6	EN/PWM

SP6682
10 Pin DFN

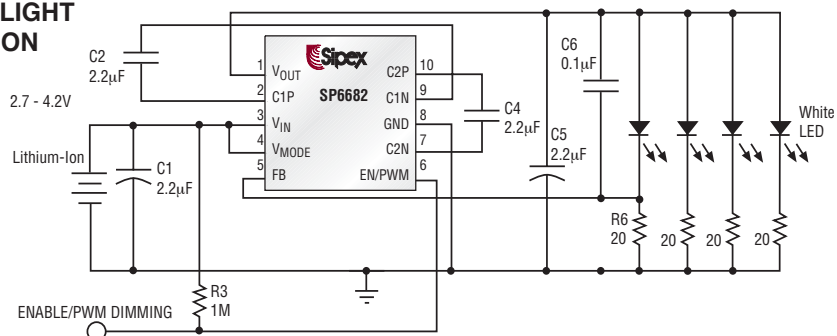*Now Available in Lead Free Packaging*

APPLICATIONS

- ■ Next Generation Mobile Phones
- ■ PDAs
- ■ 3.3V to 5.0V Conversion
- ■ Palmtop Computers
- ■ Color LCD Modules

DESCRIPTION

The SP6682 is a current regulated charge pump ideal for converting a Li-Ion battery input for driving white LEDs used in backlighting color displays or cell phone camera flash applications. The charge pump automatically switches between X1.5 and X2 modes based on the program-mable V_{MODE} voltage, providing improved efficiency over traditional methods using charge pump doubler followed by LDO. This input voltage threshold can be externally programmed by a resistor divider network for optimized efficiency at specific output voltages and currents. The SP6682 operates with an internal 600kHz clock, which reduces switching noise and improves V_{OUT} ripple. Output current or voltage can be accurately regulated by modulating the switcher between the charge pump and output capacitor. In shutdown mode, the IC disconnects the output from the input and draws less than 1.5μA current. The SP6682 is offered in a 10-pin MSOP package, and a small 10-Pin DFN Package.
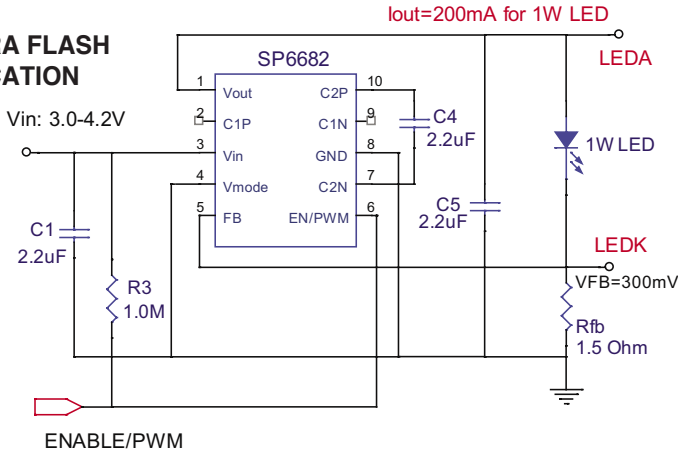
TYPICAL APPLICATION SCHEMATIC

LCD BACKLIGHT APPLICATION

TYPICAL APPLICATION SCHEMATIC

CAMERA FLASH APPLICATION

Iout=200mA for 1W LED

Vin: 3.0-4.2V

SP6682

1	Vout	C2P	10
2	C1P	C1N	9
3	Vin	GND	8
4	Vmode	C2N	7
5	FB	EN/PWM	6

LEDA

1W LED

C4 2.2uF

C5 2.2uF

LEDK

VFB=300mV

Rfb 1.5 Ohm

C1 2.2uF

R3 1.0M

ENABLE/PWM

ABSOLUTE MAXIMUM RATINGS

V_{IN}, V_{MODE}, V_{OUT} and EN/PWM .... -0.3V to 6V
V_{IN} - V_{OUT} 0.7V
Output Current (I_{OUT}) 300mA
Power Dissipation per Package - 10-pin MSOP
(derate 8.84mW/°C above +70°C) 720mW
Junction Temperature .... +125°C
Storage Temperature .... -65°C to +150°C
ESD Rating. .... 2kV HBM

These are stress ratings only and functional operation of the device at these ratings or any other above those indicated in the operation sections of the specifications below is not implied. Exposure to absolute maximum rating conditions for extended periods of time may affect reliability.

ELECTRICAL CHARACTERISTICS

Unless otherwise specified: V_{IN} =+2.7V to +5.0V, C1=C2=C4=C5=2.2μF (ceramic, ESR=0.03Ω), C3=0.1μF (ceramic) and T_{AMB} =-40°C to +85°C unless otherwise noted.

PARAMETER	MIN	TYP	MAX	UNITS	CONDITIONS
Input Voltage	2.7		5.5	V	
Quiescent Current		1.2	3	mA	V_{IN} = 4.2V, V_{OUT} = 3.6V, I_{OUT} = 100μA
Shutdown Current			1.5	μA	EN/PWM = 0.0V, V_{IN} = 5.5V
Oscillator Frequency	0.42	0.60	0.78	MHz	V_{IN} = 3.6V
V_{FB} Reference Voltage	0.275	0.306	0.337	V	
Charge Pump Output Resistance		11	18	Ω	FB = 0.0V, V_{IN} = 3.6V, I_{OUT} = 20mA, V_{MODE} = High
V_{MODE} Threshold Voltage	1.15	1.25	1.35	V	V_{IN} Falling @ 25°C
Hysteresis for Mode Transition Voltage		30		mV$_{PP}$	V_{IN} = 3.6V @ 25°C
V_{MODE} Pin Current		0.01	0.5	μA	V_{MODE} = 1.25
EN/PWM Logic Low			0.4	V	
EN/PWM Logic High	1.6			V	
EN/PWM Pin Current		0.01	0.5	μA	$V_{EN/PWM}$ = 4.2V
FB Pin Current			0.5	μA	V_{FB} = 1V
V_{OUT} Turn-On Time		175	500	μs	V_{IN} = 3.6V, FB within 90% regulation

Refer to the typical application circuit, $T_{AMB} = 25^{\circ}C$, $I_O = 60mA$ unless otherwise specified.

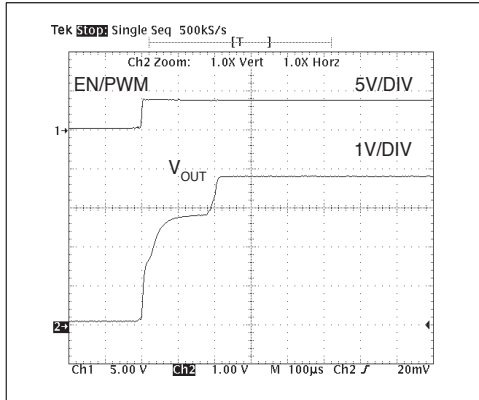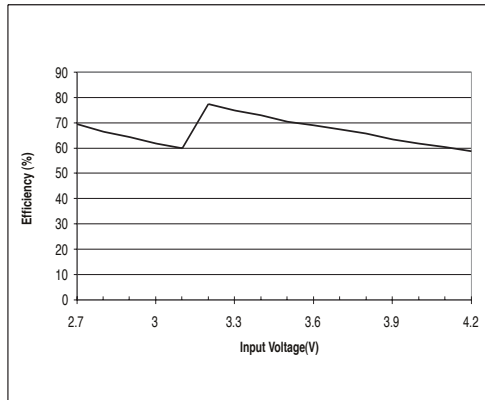*Figure 1. Output voltage turn-on time*

Figure 2. Power efficiency vs. input voltage

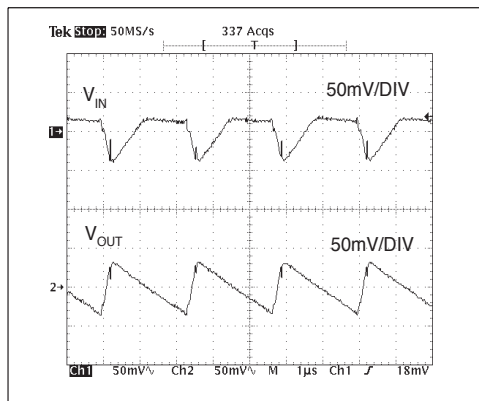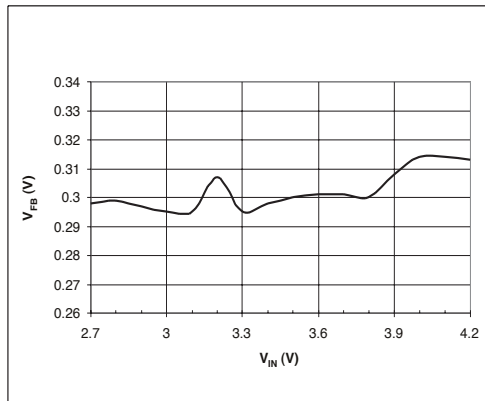*Figure 3. X2 mode voltage ripple when $V_{IN} = 2.7V$*
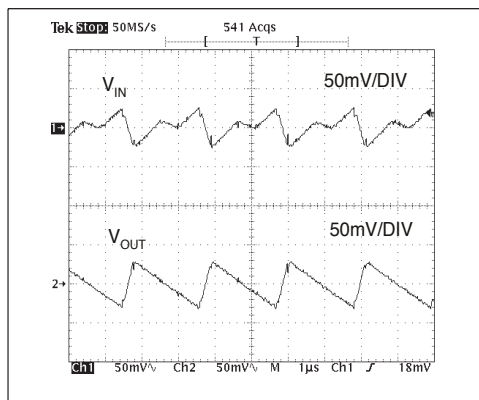

Figure 4. Feedback pin voltage vs. input voltage

Figure 5. X1.5 mode voltage ripple when $V_{IN} = 3.3V$

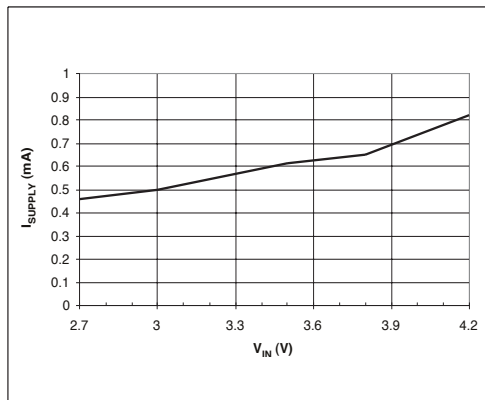*Figure 6. Quiescent current vs. input voltage*

Refer to the typical application circuit, T_{AMB} = 25°C, I_O = 60mA unless otherwise specified.
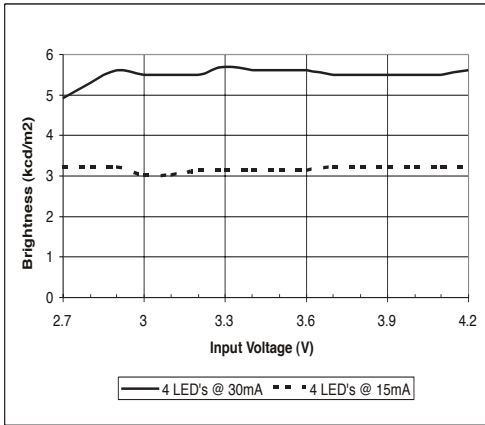

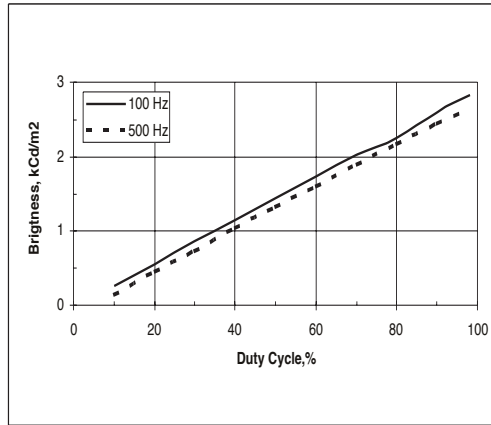*Figure 7. Brightness vs. input voltage*
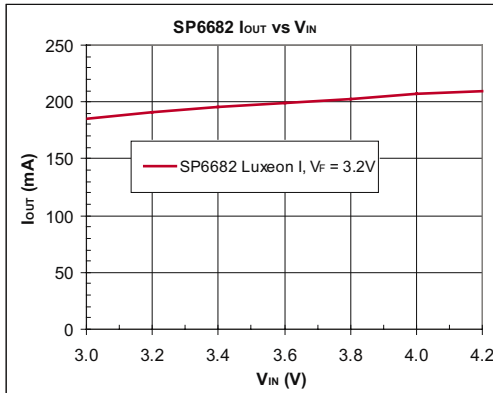

Figure 8. Brightness vs. duty cycle

Figure 9. I_{OUT} vs. V_{IN}

GENERAL OVERVIEW

The SP6682 is a current regulated charge pump ideal for converting a Li-Ion battery input for driving white LEDs used in back-lighting color displays, Cell Phone Camera Flash, PDAs, digital cameras and MP3 play-ers. The SP6682's proprietary AutoBoost feature enables the IC to automatically trans-ition from X1.5 boost mode to X2 boost mode based on battery input voltage for optimal efficiency and performance. The SP6682 is able to efficiently drive up to six 20mA white LEDs in parallel and maintain a constant brightness over a very wide operating voltage range (2.7V to 5.5V). The SP6682 operates with an internal 600kHz clock, enabling the use of small external components. Other features of SP6682 include PWM dimming control as well as complete input/out disconnect in shutdown. In shutdown mode the IC draws less than
1.5μA current. The output regulation is achieved by sensing the voltage at the feedback pin and modulating the switcher between the charge pump and output capacitor.

THEORY OF OPERATION

The SP6682 regulated charge pump block diagram consists of four main blocks (Voltage Reference, Mode Control, Clock Manager, Start-up and Charge-Pump Switches) and two comparators (V_{MODE} Comparator and V_{OUT} Comparator).

1) Voltage Reference. This block provides the 306mV and 1.25V reference voltages needed for the two comparators.

2) Mode Control. An external voltage di-vider connected to the V_{MODE} pin will define an input voltage to the mode comparator which sets the logic state of the mode selec-tion outputs to the X2 or X1.5 modes. V_{MODE} is compared to a 1.25V bandgap voltage. For example, if one makes a 158KΩ/100KΩ divider, the mode will change at 2.58 x 1.25 V = 3.23V. A comparator-based cycle-by-cycle regulation ensures that no mode change occurs during cycles.

3) Clock Manager. An internal 600 kHz clock is generated in this block. Depending on the mode control, the appropriate clock phasing is generated here and sent to the start-up and charge-pump switches block.

4) Start-up and Charge Pump Switches. During start-up, until the reference is estab-lished, this block keeps the charge pump inactive. During this period the output stays floating, and by consequence the charge pump drivers are now referenced to V_{OUT}. Charging of the output will occur (e.g. when V_{IN} is ramped up to 4.2V, V_{OUT} ramps only up to about 3V), but not to the value of V_{IN}, protecting the White LEDs from experienc-ing high input voltages. Another important operation of this block is the PWM/EN dim-ming control, which is implemented in the delay of each pump driver, so that the enable high pulse width is proportional to the delay of the individual pump switches.

5) V_{OUT} Comparator and Output Control. A 306mV reference voltage is compared to feedback output voltage to control the V_{OUT} needed for the application. Output current is set by a bias resistor from FB pin to GND pin chosen by the relationship:

$$I_{OUT} = \frac{V_{FB}}{R_{FB}}$$

where V_{FB} = 306mV.

CONFIGURING THE SP6682 AS VOLTAGE OR CURRENT SOURCE

The white LED load configuration used by customers can be discrete white LEDs or a white LED module. Inside the white LED module, there may or may not be resistors in series with the white LEDs. According to the different application requirements, the SP6682 can be configured as either a voltage source or a current source to provide solutions for these different applications, as shown in figures 10-13.

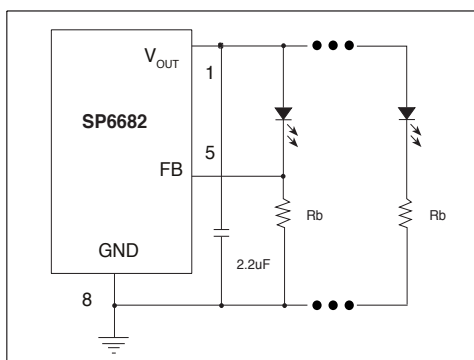Figure 10 shows a circuit using the SP6682 to drive discrete white LEDs as a current source.

Figure 10. Driving discrete white LEDs as current source

The current in one white LED current is set by the ratio of the feedback pin voltage (306mV) and the bias resistor R_B. To set the operating current, R_B can be selected by:

$$R_B = \frac{V_{FB}}{I_{LED}}$$

The current of the remaining white LEDs is set according to the similarity of the white LEDs.

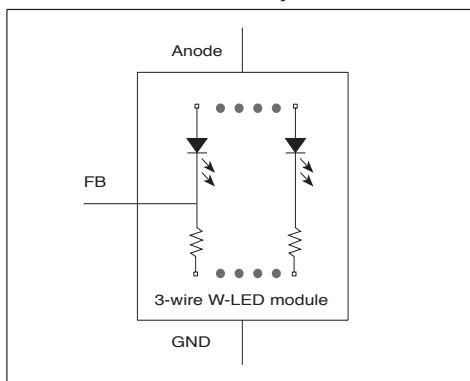A 3-wire white LED module with internal series resistors as shown in figure 11 can also be driven in this way.

Fig 11. 3-wire white LED module

In Figure 12, the SP6682 was used to drive a 2-wire white LED module without internal series resistors as a current source. The bias resistor R_B is selected to regulate the total current of the white LED module instead of the current of single LED as in Figure 10.
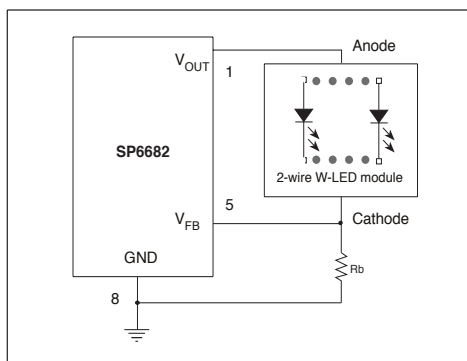

Figure 12. Driving 2-wire white LED module as current source

In this application, the bias resistor can be selected by:

$$R_B = \frac{V_{FB}}{I_{LED\,(TOTAL)}}$$

where $I_{LED(TOTAL)}$ is the total operating current of all the white LEDs.

To use the SP6682 as a voltage source for fixed voltage applications, a voltage divider is needed to program the ouput voltage, as shown in Figure 13.
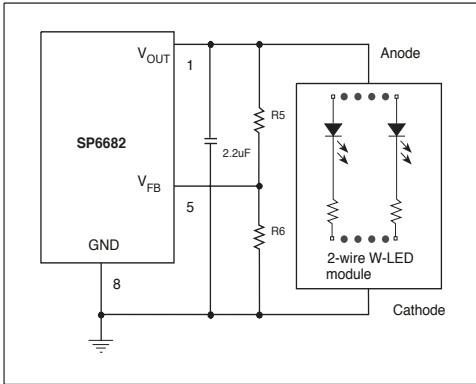

Figure 13. Driving 2-wire white LED module as voltage source

The output voltage is set by the ratio of the two resistors and the feedback control voltage as shown by:

$$V_{OUT} = \left(1 + \frac{R_5}{R_6} \right) \cdot V_{FB}$$

PROGRAMMING THE OPERATING MODE

SP6682 can automatically change from X1.5 mode to X2 mode for highest efficiency. To use this feature, divider resistors should be chosen according to the specific application, as shown in Figure 14.
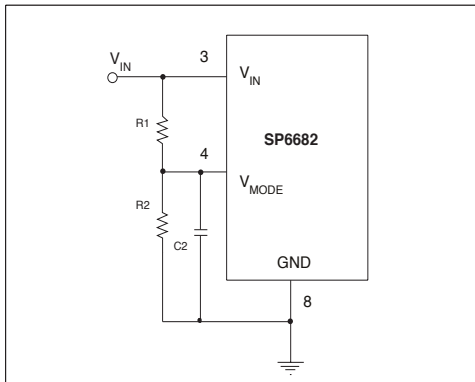

Figure 14. Programming the Vmode Resistors

The guideline for divider resistor selections is as follows: For high input voltage, the SP6682 will work in X1.5 mode. When the input voltage drops to the V_{TH} threshold voltage, it will switch to X2 mode automatically. The V_{TH} threshold voltage for mode change can be calculated by:

$$V_{TH} = (V_F + 0.306 + M \cdot I_{LED} \cdot R_{OUT})/1.5$$

Where V_F and M are the forward voltage and number of the white LEDs, R_{OUT} is the output resistance of the SP6682.

The equation for the voltage divider R_1 and R_2 with $V_{MODE} = 1.25V$ is:

$$V_{TH} = 1.25V \cdot (1+R_1/R_2)$$

which can be expressed as R1:

$$R_1 = (V_{TH} / 1.25 - 1) \cdot R_2$$

For the typical SP6682 application, Using V_F=3.6V, M=4, I_{LED}=15mA, R_{OUT}=16Ω, the V_{TH} will be 3.24V. Select R_2=100kΩ, then R_1=158kΩ.

CAPACITOR SELECTION

Ceramic capacitors are recommended for their inherently low ESR, which will help produce low peak to peak output ripple, and reduce high frequency spikes.

The fly capacitor controls the strength of the charge pump. Selection of the fly capacitor is a trade-off between the output voltage ripple and the output current capability. Decreasing the fly capacitor will reduce the output voltage ripple because less charge will be delivered to the output capacitor. However, smaller fly capacitors lead to larger output resistance, thus decreasing the out-

put current capability and the circuit efficiency. Place all the capacitors as close to the SP6682 as possible for layout. Increasing the value of the input and output capacitors could further reduce the input and output ripple.

Refer to Table 1 for some suggested low ESR capacitors.

$$\frac{I_1}{I_2} = \frac{V_{OUT} - V_{F1}}{V_{OUT} - V_{F2}}$$

where I_1, I_2 are the operating current of the white LEDs and V_{F1}, V_{F2} are the forward voltage of the white LEDs.

MANUFACTURER	PART NUMBER	CAPACITANCE/ VOLTAGE	CAPACITOR/ SIZE/TYPE	ESR AT 100kHz
TDK	C2012X5R1A225K	2.2µF/10V	0805/X5R	0.030Ω
TDK	C2012X5R0J475K	4.7µF/6.3V	0805/X5R	0.020Ω
MURATA	GRM188R60J225KE01D	2.2µF/6.3V	0603/X5R	0.030Ω
MURATA	GRM219R60J475KE01D	4.7µF/6.3V	0805/X5R	0.020Ω

Table 1:   **Suggested Low ESR Capacitors**

BRIGHTNESS CONTROL USING PWM

Dimming control can be achieved by applying a PWM control signal to the EN/PWM pin. The brightness of the white LEDs is controlled by increasing and decreasing the duty cycle of the PWM signal. While the operating frequency range of the PWM control is from 60Hz to 700Hz, the recommended maximum brightness frequency range of the PWM signal is from 60Hz to 200Hz. A repetition rate of at least 60Hz is required to prevent flicker.

BRIGHTNESS MATCHING

For white LEDs, the forward voltage drop is a function of the operating current. However, for a given current, the forward voltage drops do not always match due to normal manufacturing tolerances, thus causing uneven brightness of the white LEDs.

In Figure 15, assume high-precision bias resistors were used, the operating current ratio of two different branches can be easily derived as shown by:

Since the brightness of the white LED is proportional to the operating current, for better brightness matching, a higher output voltage could be used. This could be done by using a larger resistor, as shown in Figure 15. R_{B2} is used to bias the operating current of the white LED, R_{B1} is used to increase the output voltage. Better brightness matching was achieved at the cost of the power wasted on the bias resistor.
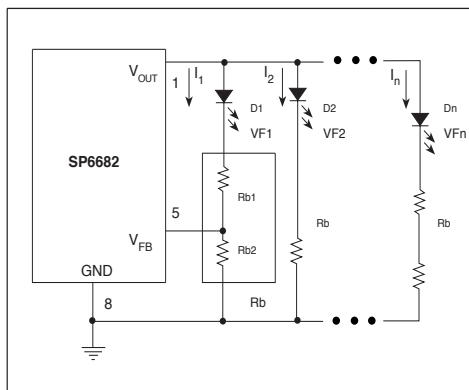

Figure 15. Increasing brightness matching

POWER EFFICIENCY

The efficiency of driving the white LEDs can be calculated by:

$$\eta = \frac{V_F \cdot I_F}{V_i \cdot I_i} = \frac{V_F \cdot I_F}{V_i \cdot (n \cdot I_F + I_Q)} \approx \frac{V_F}{V_i \cdot n}$$

Where V_i, I_i are input voltage and current V_F, I_F are the forward voltage and operating current of White LEDs; I_Q is quiescent current, which is considered small compared with I_F; n is the boost ratio (X1.5 or X2).

SP6682 HIGH VOLTAGE WHITE LED DRIVER

The SP6682 can also be configured as a high voltage boost converter to drive more than 10 white LEDs. Figure 16 shows the schematic of this application as well as actual data showing efficiency of > 85%. By using an external inductor, MOSFET and diode, high output voltages can be generated to drive 12 white LEDs (2 branches -- each branch has 6 white LEDs in series). The current through the white LEDs is determined by:

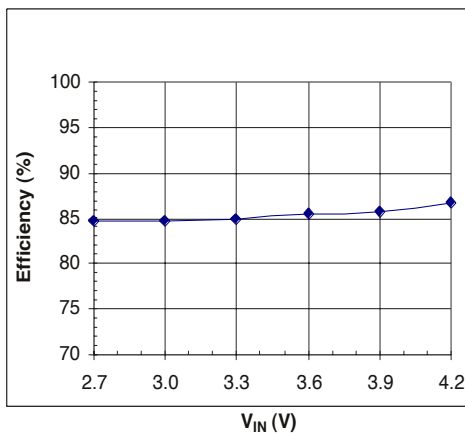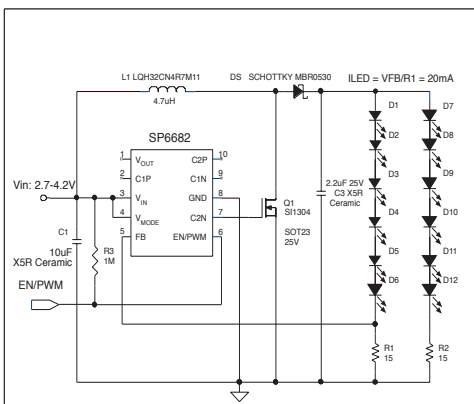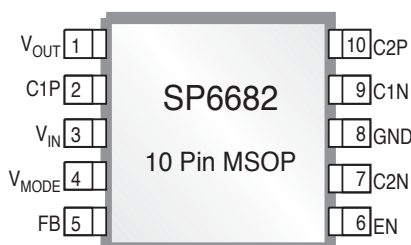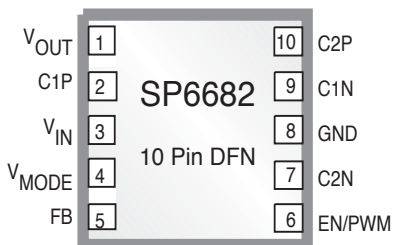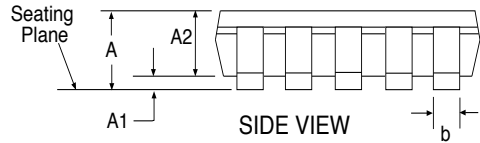$$I_{LED} = \frac{V_{FB}}{R_1}$$

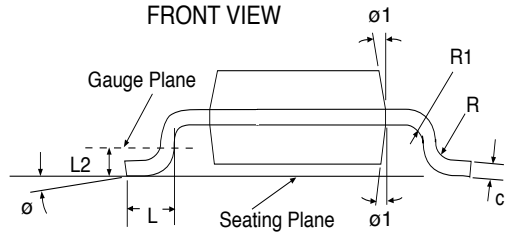*Figure 16. Using SP6682 as a High Voltage White LED Driver*

TOP VIEW

FRONT VIEW

Gauge Plane

Seating Plane

SIDE VIEW

Pin #1 designator
to be within this
INDEX AREA
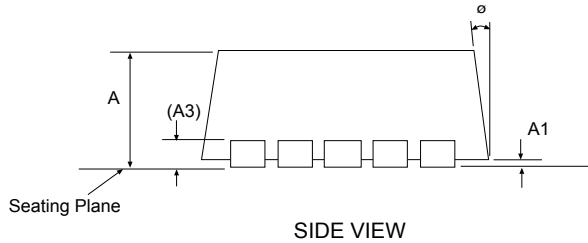(D/2 * E1/2)
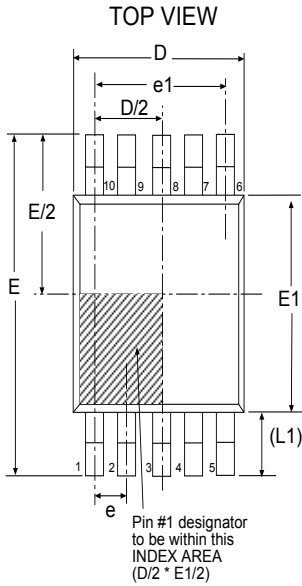
10 Pin MSOP		JEDEC MO-187		Variation BA	
SYMBOL	Dimensions in Millimeters: Controlling Dimension			Dimensions in Inches Conversion Factor: 1 Inch = 25.40 mm		
	MIN	NOM	MAX	MIN	NOM	MAX
A1	0.00	-	0.15	0.000	-	0.006
c	0.08	-	0.23	0.004	-	0.009
R	0.07	-	-	0.003	-	-
R1	0.07	-	-	0.003	-	-
ø	0º	-	8º	0º	-	8º
ø1	5º	-	15º	5º	-	15º
A	-	-	1.10	-		0.043
A2	0.75	0.85	0.95	0.030	0.034	0.038
b	0.17	-	0.33	0.007	-	0.013
D	3.00 BSC			0.118 BSC		
E	4.90 BSC			0.193 BSC		
E1	3.00 BSC			0.118 BSC		
e	0.50 BSC			0.020 BSC		
e1	2.00 BSC			0.079 BSC		
L	0.40	0.60	0.80	0.016	0.024	0.032
L1	0.95 REF			0.037 REF		
L2	0.25 BSC			0.010 BSC		
SIPEX Pkg Signoff Date/Rev:				JL Aug09-05 RevA		

TOP VIEW

SIDE VIEW

BOTTOM VIEW

3x3 10 Pin DFN	JEDEC MO-229		VARIATION VEED-5		
SYMBOL	Dimensions in Millimeters: Controlling Dimension		Dimensions in Inches Conversion Factor: 1 Inch = 25.40 mm		
	MIN	NOM	MAX	MIN	NOM	MAX
A	0.80	0.90	1.00	0.032	0.036	0.039
A1	0.00	0.02	0.05	0.000	0.001	0.002
A3	0.20 REF			0.008 REF		
K	0.20	-	-	0.008	-	-
ø	0º	-	14º	0º	-	14º
b	0.18	0.25	0.30	0.008	0.010	0.012
D	3.00 BSC			0.119 BSC		
D2	2.20	-	2.70	0.087	-	0.106
E	3.00 BSC			0.119 BSC		
E2	1.40	-	1.75	0.056	-	0.069
e	0.50 BSC			0.020 BSC		
L	0.30	0.40	0.50	0.012	0.016	0.020
SIPEX Pkg Signoff Date/Rev:			JL Aug09-05 / RevA		

Part Number	Top Mark	Operating Temperature Range	Package Type
SP6682EU	SP6682EU	-40°C to +85°C	10 Pin MSOP
SP6682EU/TR	SP6682EU	-40°C to +85°C	10 Pin MSOP
SP6682ER	SP6682ERYWW	-40°C to +85°C	10 Pin DFN
SP6682ER/TR	SP6682ERYWW	-40°C to +85°C	10 Pin DFN

Available in lead free packaging. To order add "-L" suffix to part number.

Example: SP6682ER/TR = standard; SP6682ER-L/TR = lead free

/TR = Tape and Reel

Pack quantity is 2,500 for MSOP and 3,000 for DFN.