## LOW VOLTAGE LED DRIVER USING L6920D, L4971 AND L6902D

1 INTRODUCTION

High brightness LEDs are becoming a prominent source of light and often have better efficiency and reliability when compared to that of conventional light sources. While LEDs can operate from an energy source as simple as a battery and resistor, most applications require an efficient energy source not only for the reduction of losses, but also for the lumen maintenance of the LED itself. STMicroelectronics has developed the following non-isolated DC-DC constant current LED driver to aid designers in developing a low cost and efficient platform for driving high brightness LEDs.

This application note will cover 3 DC-DC power supplies to drive high intensity LEDs.

1 The L6920D boost converter to drive 1 LED for a flash light application
2 The L4971 buck converter to drive 1 to 9 LEDs
3 The L6902D buck converter to drive 1 to 6 LEDs

Figure 1. Reference Design Boards:
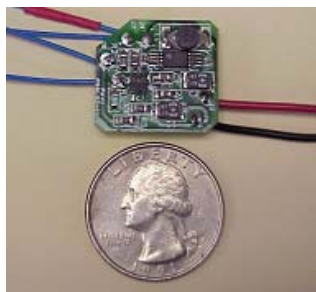
L6920D   L4971   L6902D

2 L6920D LED DRIVER

White LEDs are gaining popularity as sources of illumination because of their high efficiency and reliability. Typical forward voltage drop of a white LED is approximately 3.5V. When these LEDs are powered from a single or two cell batteries, a boost converter is needed to boost the voltage to drive the LEDs.

2.1 L6920D Description

L6920D is a high efficiency step-up converter requiring very few external components to realize the conversion from the battery voltage to the selected output voltage or current. The start-up is guaranteed at 1V and the device is operating down to 0.6V. The device has very low quiescent current, only 10μA. Internal synchronous rectifier is implemented with a 120mΩ P-channel MOSFET, replacing the conventional boost diode, to improve the efficiency. This also implies a reduced cost in the application since no external diode required.

Following is the block diagram of L6920D.

**Figure 2. Block diagram of L6920D**
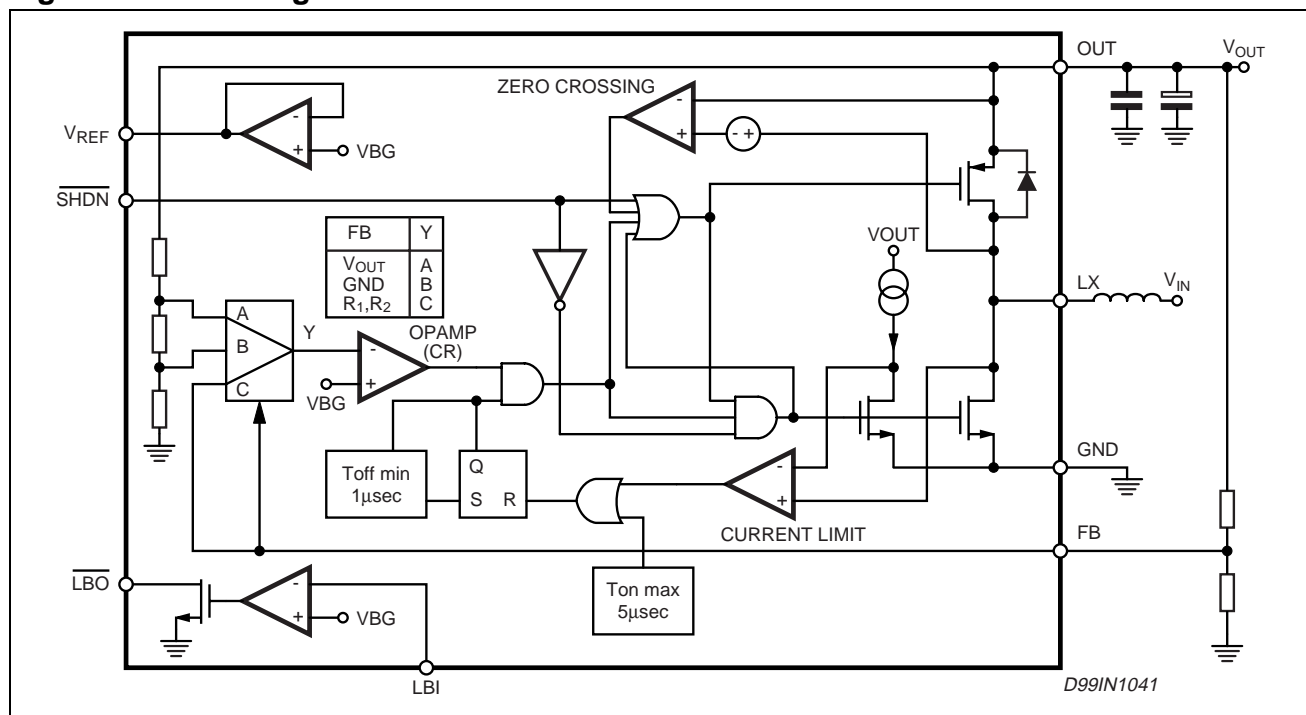
In L6920D, the control is based on the comparator that continuously checks the status of the feedback signal. If the feedback voltage is lower than reference value, the control function of the L6920D directs the energy stored in the inductor to be transferred to the load. This is accomplished by alternating between two basic steps:

– Ton phase: the bottom MOFSET Q1 is turned on, and the inductor is charged. The switch is turned off if the current reaches 1A or after a maximum on-time set to 5s.

– Toff phase: the bottom MOSFET Q1 is turned off, and top MOSFET Q2 is turned on. The energy stored in the inductor is transferred to the load for at least a minimum off time of 1s. After this, the synchronous switch is turned off as soon as the feedback signal goes lower than reference or the current flowing in the inductor goes down to zero.

2.2 Circuit Description

The circuit shown in figure 3 is a constant current control to provide constant luminosity from the LED. A current sensing resistor is in series with the white LED is used to provide the current feedback. The feedback reference voltage for the controller is 1.23V. If this voltage level is directly feedback from the current sensing resistor, the loss in the resistor will be too high. The circuit uses a low value sense resistor, R1 to reduce the dissipation and an op-amp to amplify the current sense voltage back up to the required 1.23V level.

Figure 3. Schematic of L6920D LED driver
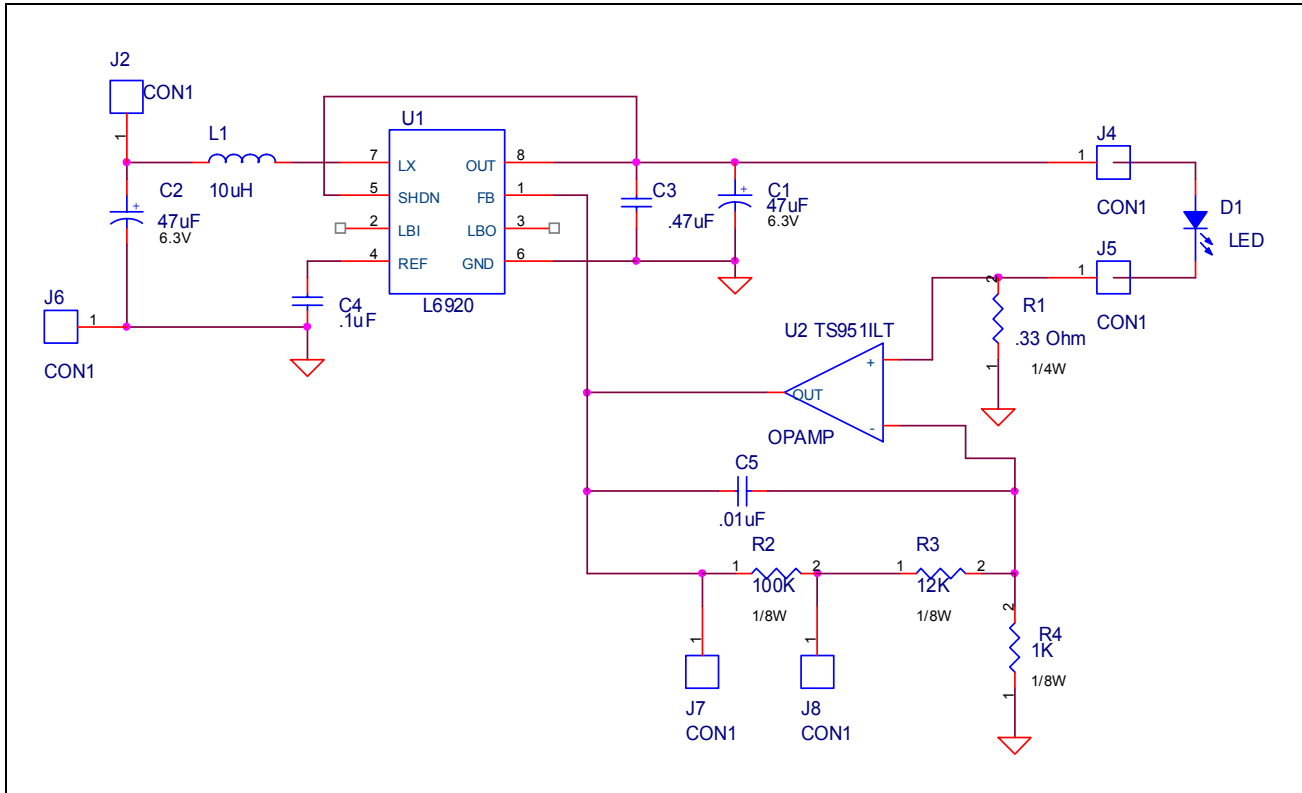
From the circuit, the control rule is: $I_{LED} \cdot R1 \cdot K = Vref$

where I_{LED} is the current through the LED; R1 is the current sensing resistor, K is the gain of the OP AMP, and Vref is the reference voltage.

Therefore, the LED current will be $I_{LED} = \dfrac{V_{REF}}{R1 \cdot K}$

In the reference circuit, there are two gains. When J7 and J8 are shorted, K1=1+R3/R4. When J7 and J8 are open, K2=1+(R3+R2)/R4.

In the circuit, R1 = 0.33Ω; R2 = 100 kΩ; R3 = 12 kΩ; R4 = 1 kΩ. the current level of the LED can be I_{LED1} = 280mA or I_{LED2} = 32 mA.

Following are some typical waveforms at Vin=2.5 V.

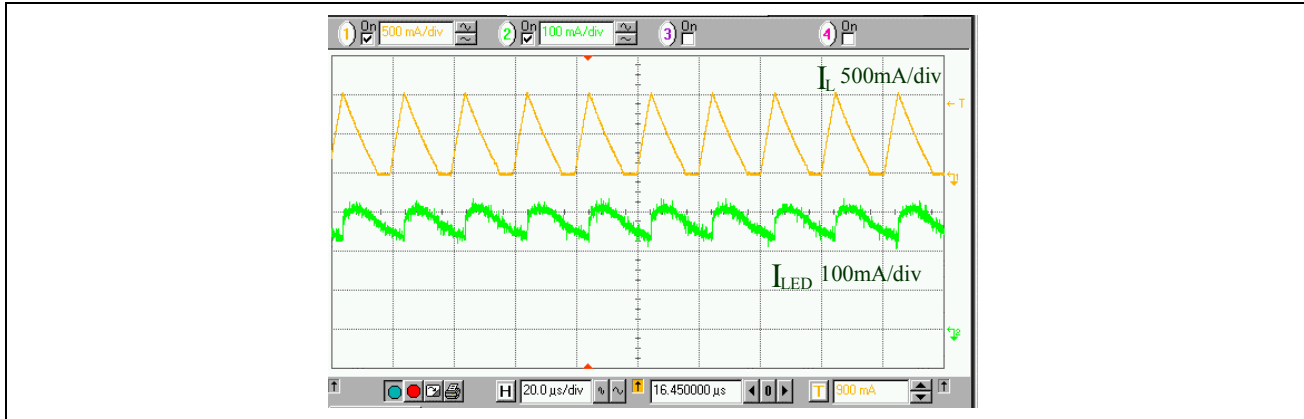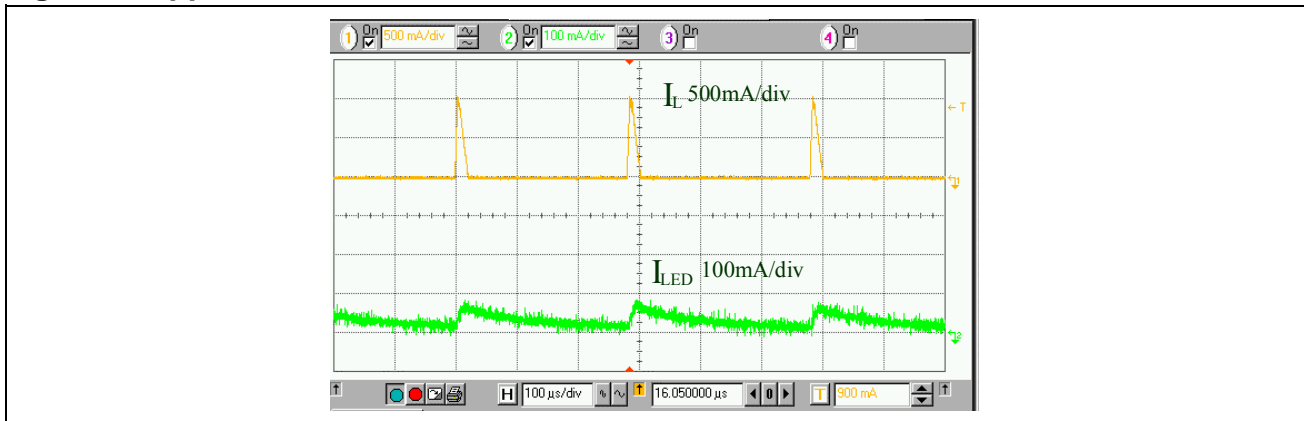**Figure 4. Upper trace: inductor current; lower track: LED current**

Figure 5. Upper trace: inductor current; lower track: LED current

from the waveforms, the inductor peak current is limited at 1A. the maximum load current is defined by following relationship:

$$I_{load\_lim} = \frac{Vin}{Vout} \cdot I_{lim} - \left(T_{off\ min} \cdot \frac{Vout - Vin}{2 \cdot L}\right) \cdot \eta$$

where η is the efficiency, I_{lim} =1A, and T_{offmin} =1µs.

When the load is heavier than I_{load_lim}, the regulation will be lost, and the inductor current will go to continuous mode. Fig. 6 and Fig. 7 show that the circuit loses the regulation, but the circuit is running at its maximum duty cycle.

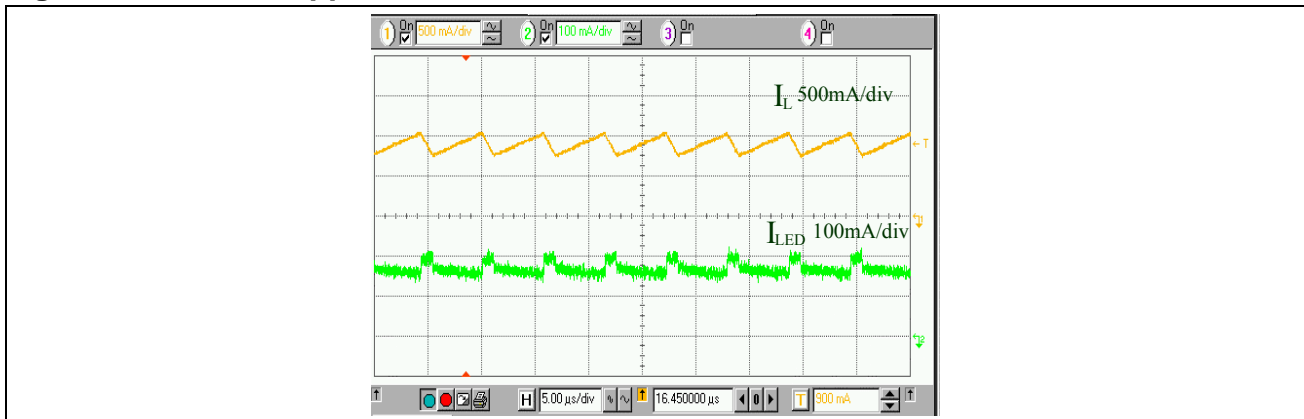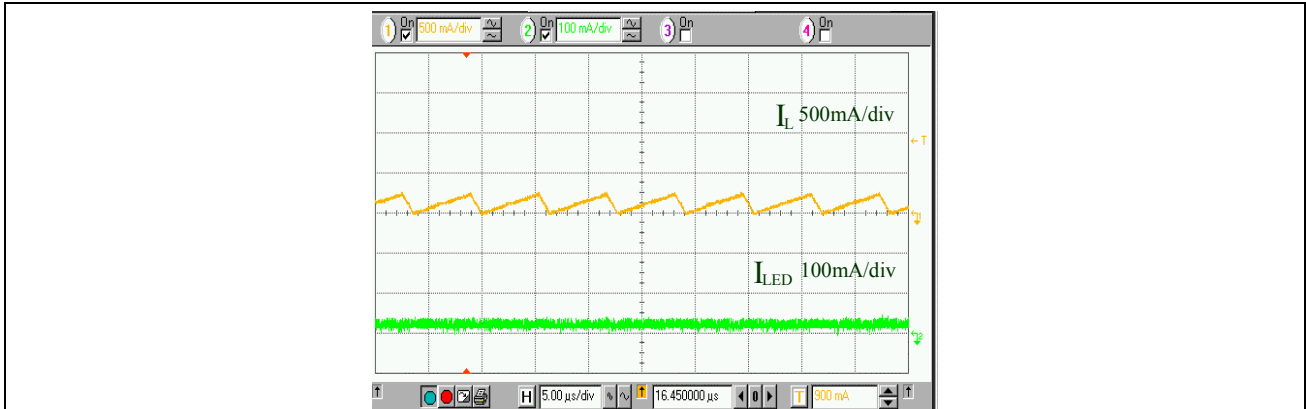**Figure 6. Vin = 1V; upper trace: inductor current; lower trace: LED current**

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Figure 7. Vin = 0.6V; upper trace: inductor current; lower trace: LED current

Fig. 8 shows the efficiency of the driver at different load and input voltages.
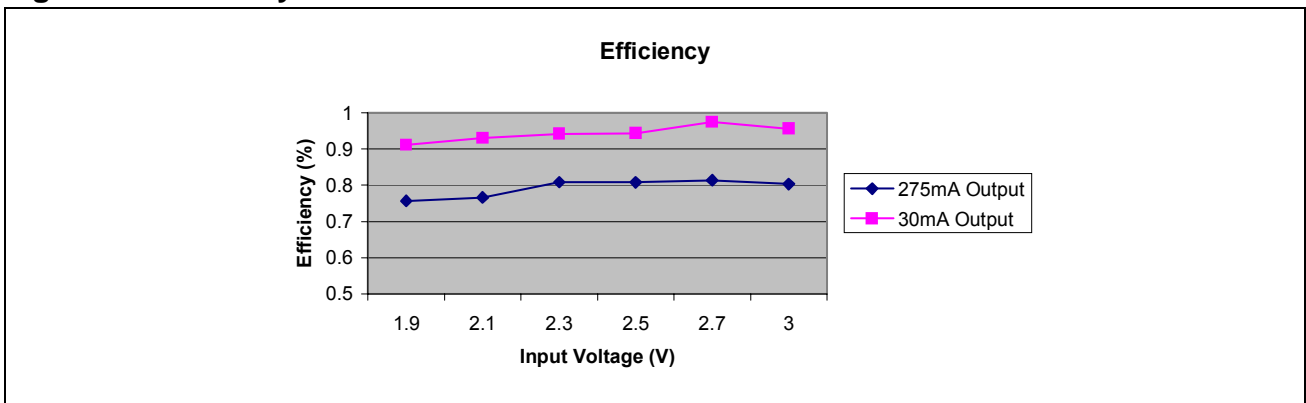
Figure 8. Efficiency curve

Table 1. Bill of Material:

Ref	Value
C2,C1	47uF 6.3V Electro sm
C3	.47uF 0805
C4	.1uF 0805
C5	.01uF 0805
L1	10uH sm inductor
R1	.33 Ohm 1% 1/4W 0805
R2	100K 5% 0805
R3	12K 5% 0805
R4	1K 5% 0805
U1	L6920D Tssop8
U2	TS951ILT sot23

Figure 9. Size of the demo board
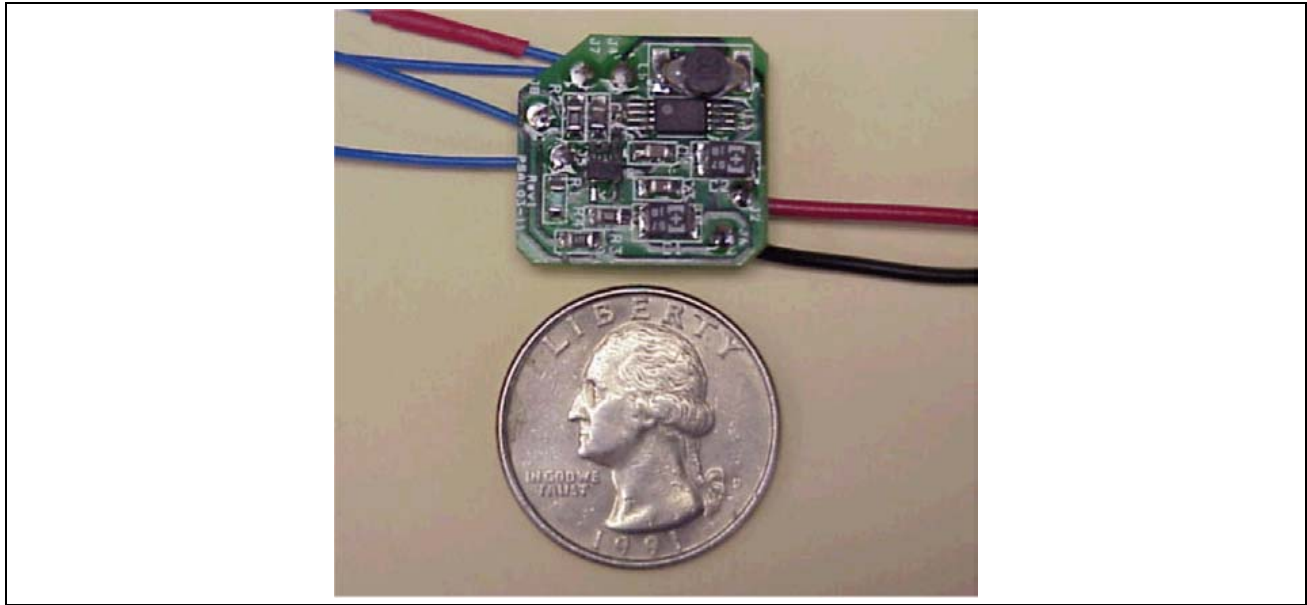
3 L4971 BUCK LED DRIVER:

For applications that use multiple LEDs it is better to drive LEDs in series rather than parallel.

3.1 LED parameters;

As shown below, the LED voltage drop tolerance varies by ±16.6% for the white LED. Different colors will have different typical voltage drop. For this reason, it is recommended that the LEDs be connected in series rather than parallel. If connected in parallel, the current would not be shared equally between the multiple LEDs due to the differences in forward voltage drop. Different brightness would result depending on individual voltage drop of the string of LEDs. With the LEDs connected in series the same current flows through each LED and the output will be better matched.

Below is the forward voltage drop spec sheet from Luxeon Star Technical Data Sheet DS23

Table 2.

| Color	Forward Voltage V_F (V)			Dynamic Resistance (Ω) R_D	Temperature Coefficient of Forward Voltage (mV/°C) $\Delta V_F / \Delta T_J$
	Min.	**Typ.**	**Max.**		
White	2.79	3.42	3.99	1.0	-2.0
Green	2.79	3.42	3.99	1.0	-2.0
Cyan	2.79	3.42	3.99	1.0	-2.0
Blue	2.79	3.42	3.99	1.0	-2.0
Royal Blue	2.79	3.42	3.99	1.0	-2.0
Red	2.31	2.85	3.27	2.4	-2.0
Amber	2.31	2.85	3.27	2.4	-2.0

The brightness is directly proportional to the current driving the LED. A test was conducted in a closed box with a white LED mounted 12 inches away from the light meter. The results showed a linear relationship between current and light output. The graph in figure 2.3 also shows the relation between current and forward drop of the LED.

When driving LEDs from a DC-DC buck topology the minimum voltage input that the power supply will operate, the maximum voltage input and the maximum power capability of the unit must be taken into account. Table 2.2 shows the capability of the L4971 and L6902D reference designs for minimum input voltage and the maximum input voltage.

Table 3.

| Control	V in	# LEDs	Current
L6902D	8	1	350mA
L6902D	25	6	350mA
L4971	20	5	220-400mA
L4971	55	9	220-400mA

Figure 10.
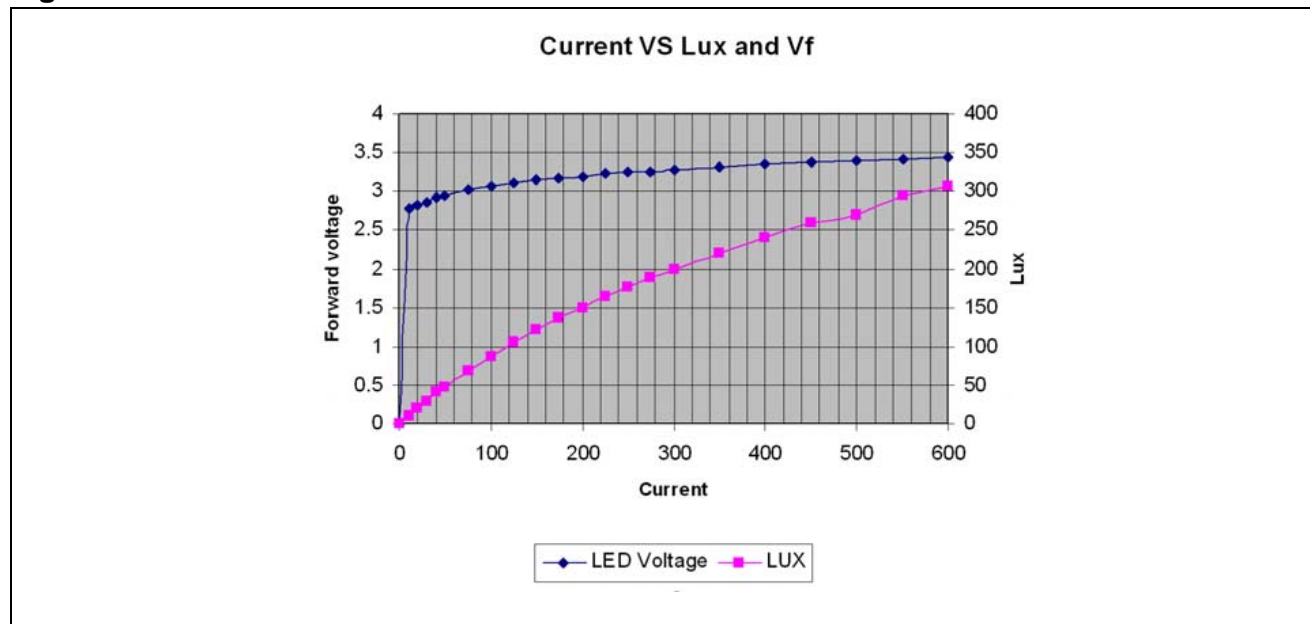
3.2 L4971 LED Driver

The L4971 is a step down monolithic power switching regulator able to deliver 1.5A. Its construction is BCD mixed technology using an internal D-MOS transistor with low Rdson to obtain high efficiency and high switching speeds. Features of this DC-DC converter are pulse by pulse current limit; hiccup mode for short circuit protection, voltage feed forward, soft start and thermal shutdown. Typically it is used for regulating an output voltage. An output current can also be regulated by sensing the voltage drop across a sense resistor, Rs as shown on the following schematic.

Figure 11.
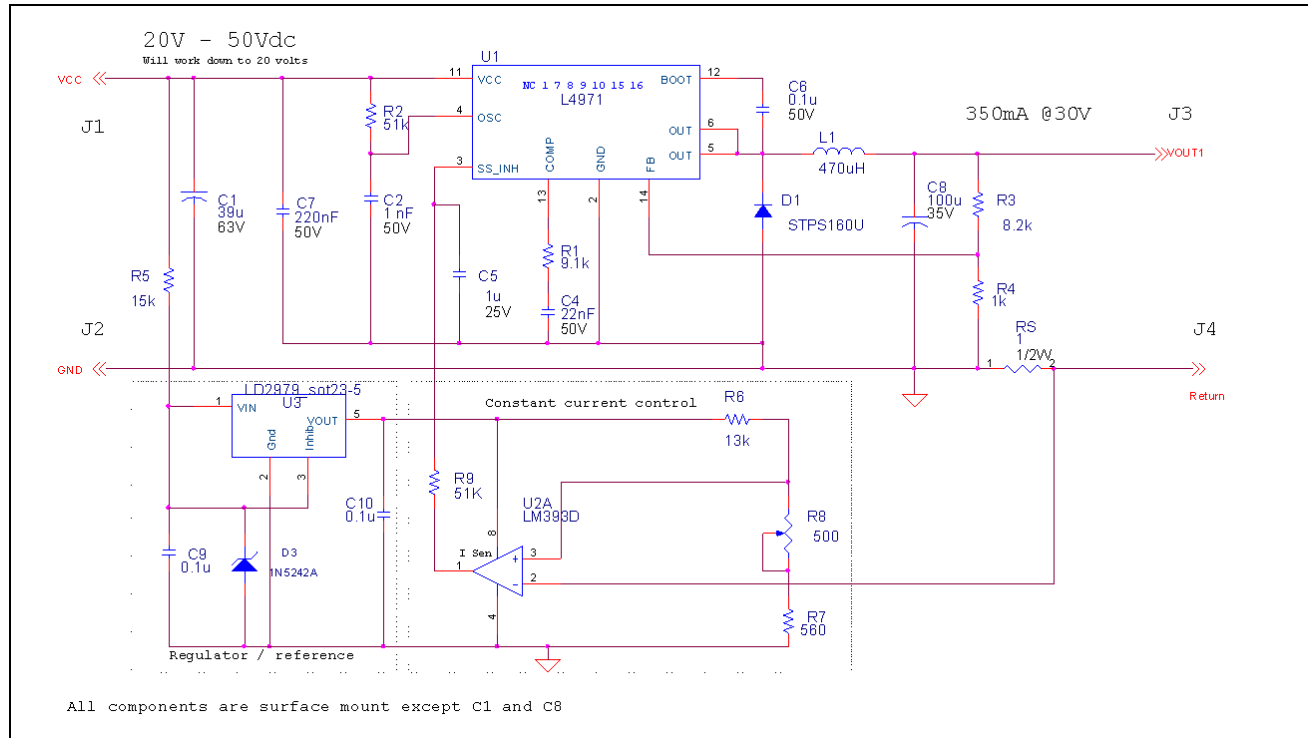
3.3 Circuit description:

The input ranges from 20 volts to 55 volts. The switching frequency is set by

$$F_{SW} = \frac{1}{R_{osc} \cdot C_{osc} \ln\left(\frac{6}{5}\right) + 100 \cdot C_{osc}}$$

where R_{osc} and C_{osc} represent R2 and C2.

The minimum voltage for the L4971 is 8 volts but the regulator-reference U3 needs a minimum of 20 volts to stay in regulation. A higher breakdown voltage regulator can be used to achieve a wider range of input. U3 provides power to the LM393 and a reference for the comparator input. This voltage is compared to the voltage drop across Rs to maintain it at the same voltage set by the potentiometer R8. The voltage drop across the resistor is proportional to the current following through it by:

$$Iout = V(U2Apin3)/Rs.$$

The output of the LM393 turns on and off to adjust the voltage at the slow start pin. The slow start voltage is directly related to the output regulation thus achieving a constant current output. The L4971 regulates by adjusting the duty cycle to maintain a constant output. R9 sets the gain of the loop by controlling the discharge rate. L1 and C8 form the output filter to smooth out the current. The inductor required is calculated at the worse case which is max input line and minimum LEDS. This gives the minimum duty cycle and maximum time that the inductor has to supply current to the load.

$$D_{max} = \frac{V_o + V_f}{V_{in\ min} + V_f} \quad D_{min} = \frac{V_o + V_f}{V_{in\ min} + V_f} \quad L_o = (V_o + V_f) \cdot \frac{(1 - D_{min})}{\Delta I_o \cdot f_{sw}}$$

ΔI_o is the current ripple set by the application, usually 10% of the max current.

R3 and R4 set the maximum voltage to 30 volts. R8 will adjust the constant current output from 220 mA to 400 mA.

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Table 4. Part List

tem	Qty	Ref	Part Tolerance		Description
1	1	C1	39u	63V	P10339-ND
2	1	C2	1nF	50V	sm ceramic
3	1	C4	22nF	50V	sm ceramic
4	1	C5	1u	25V	sm PCC1893CT
5	1	C6	0.1u	50V	sm ceramic PCC1893CT
6	1	C7	220nF	50V	sm ceramic
7	1	C8	100u	35V	P10294
8	2	C9,C10	0.1u		sm ceramic
9	1	D1	STPS160U		ST
10	1	D3	1N5242A		12V zener
11	1	L1	470uH		Coilcraft DO3316P-474
12	1	RS	1	1/2W	sm 2510
13	1	R1	9.1k		
14	2	R9,R2	51k		
15	1	R3	8.2k		
16	1	R4	1k		
17	1	R5	15k		
18	1	R6	13k		
19	1	R7	560		
20	1	R8	500		36G52-ND
21	1	U1	L4971		ST
22	1	U2	LM393D		ST
23	1	U3	LD2979_sot23-5		ST

The output voltage can be changed by readjusting the resistor divider R3 and R4 to allow a higher output voltage to drive as many as 15 LEDs of typical forward voltage drop.
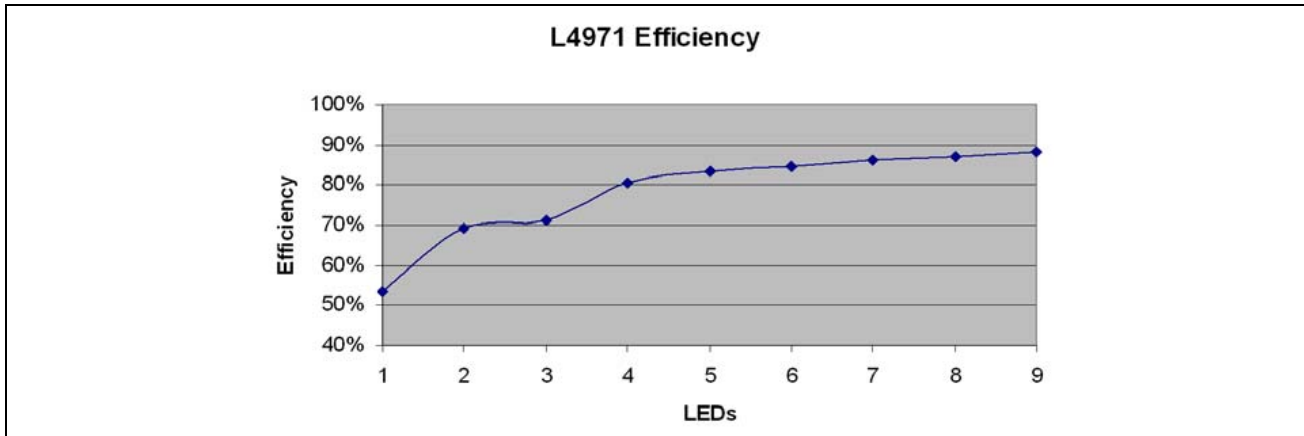
3.4 Results:

With a minimum input voltage of 20 V, up to 5 LEDs can be driven and with 33 V to 55 V input, 9 LEDs can be driven limited by the output voltage set at 30 volts.

Figure 12. Current regulation:

L4971 Current VS LEDs
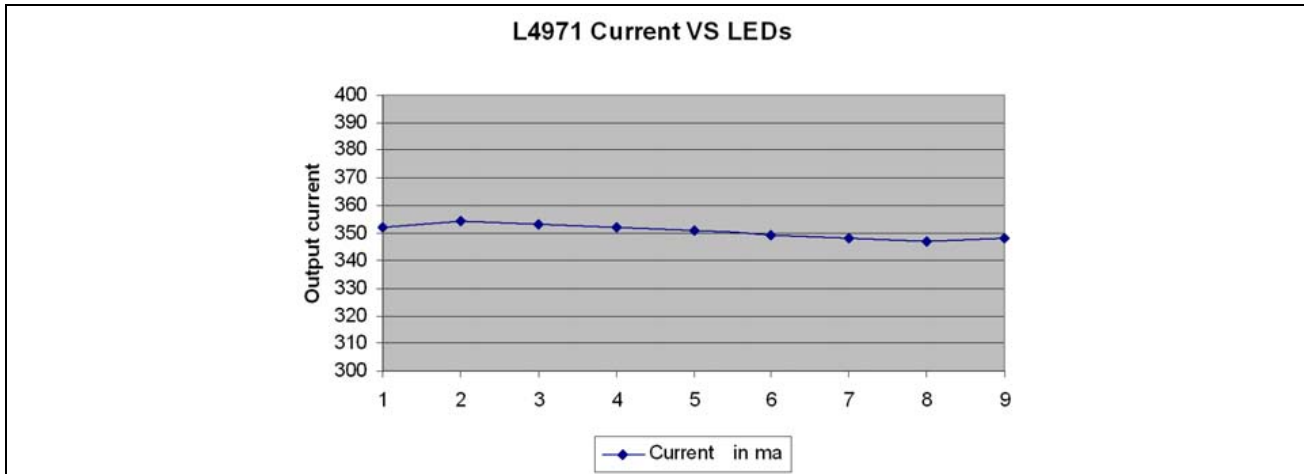
The current regulation is ± 1% for the range of 1 to 9 LEDs or a voltage range of 3.3 volts to 29 volts output.

Figure 13. Efficiency at 55V input:

L4971 Efficiency

The efficiency differences shown in figure 13 are primarily related to differences in the output power. As the number of LEDs increases, the output power also increases. However, the losses in the system remain relatively constant over the range so the efficiency increases with the number of LEDs.

Figure 14. Ripple current

4 L6902D BUCK LED DRIVER:

Another buck topology reference design that is much simpler, less expensive and requires fewer external components is the L6902D LED driver. The features of the L6902D are:

4.1 L6902D Description

– Up to 1A of output current

– Input voltage from 8V to 36V

– Built in 5% output current accuracy

– 250KHz internally fixed frequency

– Adjustable current limit

– Thermal shut down

The L6902D is a complete and simple step down switching regulator with adjustable constant voltage and constant current. By means of a current sense resistor set to give a 0.1V drop across it, the current ca be set to any desired value up to 1 amp. Iout=0.1V/Rsense.

Figure 15. Internal Block Diagram:
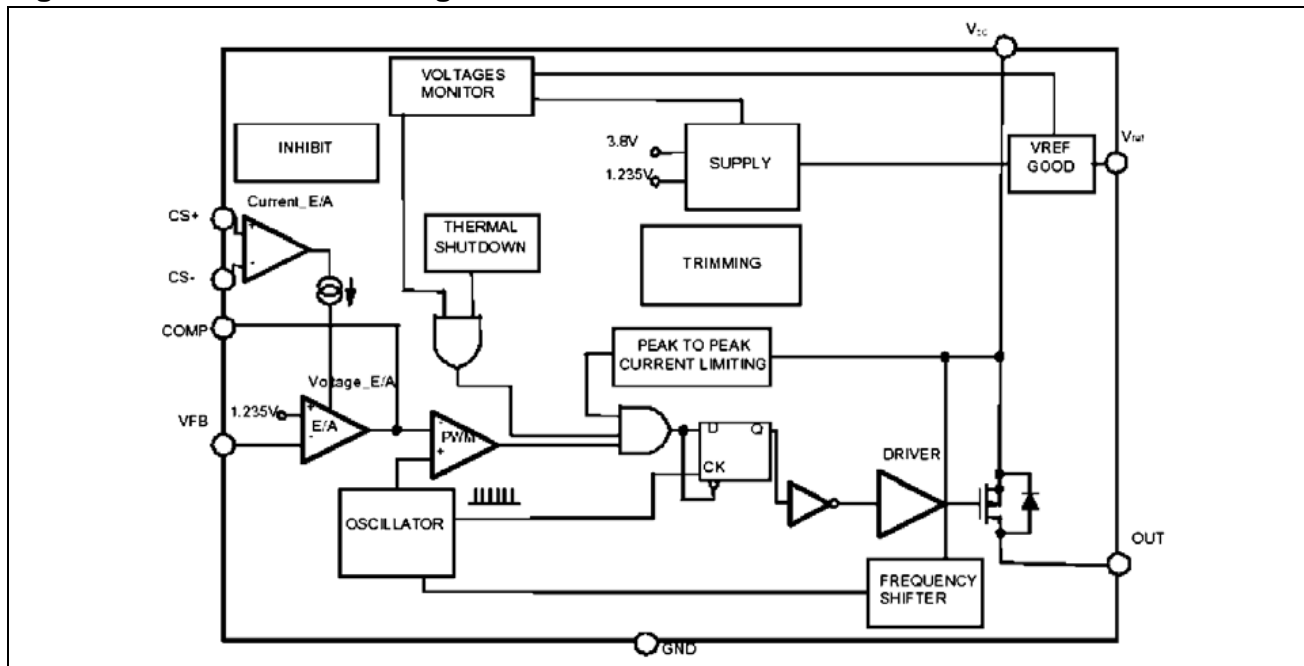
The L6902D contains a voltage and a current error amplifier with an internal reference of 3.3V and 1.235 with a tolerance of ±2%. Most of the external circuits of the previous design are incorporated inside this battery charger chip. This 8 pin chip minimizes pin count by fixing the switching frequency and allowing 2 pins for current sensing, 1 for sensing the output voltage.

Figure 16. Schematic
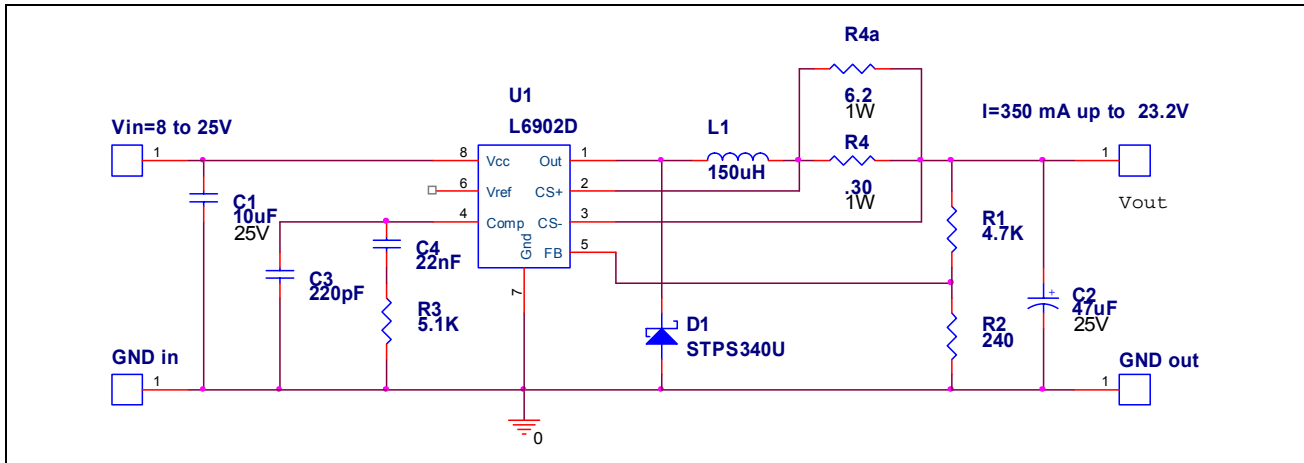
4.2 Circuit description:

The IC can operate up to 36 volts. The 25 volt input capacitor was the restricting factor for the input and output voltage. More LEDs can be driven if a 35 volt cap is used for C1 and C2. C3, C4, and R3 stabilize the feedback loop. R1 and R2 set the output voltage limit to 23.2 volts, below the rating of the output capacitor. D1 recirculates the current when the internal 250mΩ P-channel DMOS transistor is turned off. R4, 0.3 ohms 1% standard resistor, sets the current to 330mA. R4a, 6.2 ohms tweaks it to 350mA for the precise industry standard. L1 is determined as shown in the Table 4.

Table 5. BOM:

| Qty	Ref	Part	Voltage	Cat #
1	C1	10uF	25V	PCC2243CT
1	C2	47uF	25V	P10267
1	C3	220pF		PCC221BVCT
1	C4	22nF		PCC2283CT
1	D1	STPS340U	ST	STPS340U
1	L1	150uH	350ma	MOS-6020-154MXB
1	R1	4.7K		P3.9KGCT
1	R2	240		P240GCT
1	R3	5.1K		P5.1KGCT
1	R4	.30	1W	71-WSL2010-0.332
1	R4a	6.2	1W	71-WSL2010-0.332
1	U1	L6902D	ST	L6902D

4.3 Results:

With a minimum of 8 volts, 1LED can be driven and with the maximum of 25 volts, up to 6 LEDs can be driven.
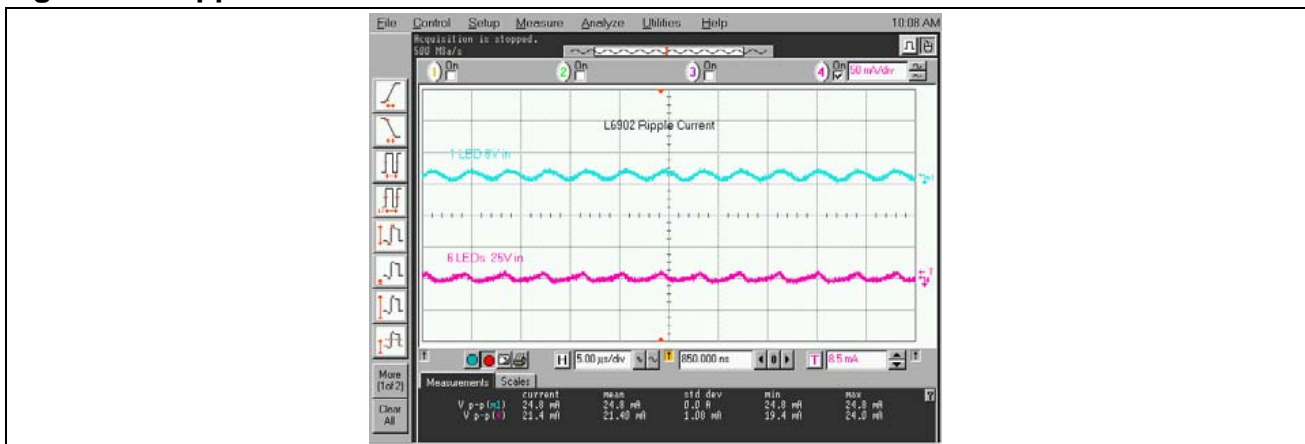
Figure 17. Current regulation
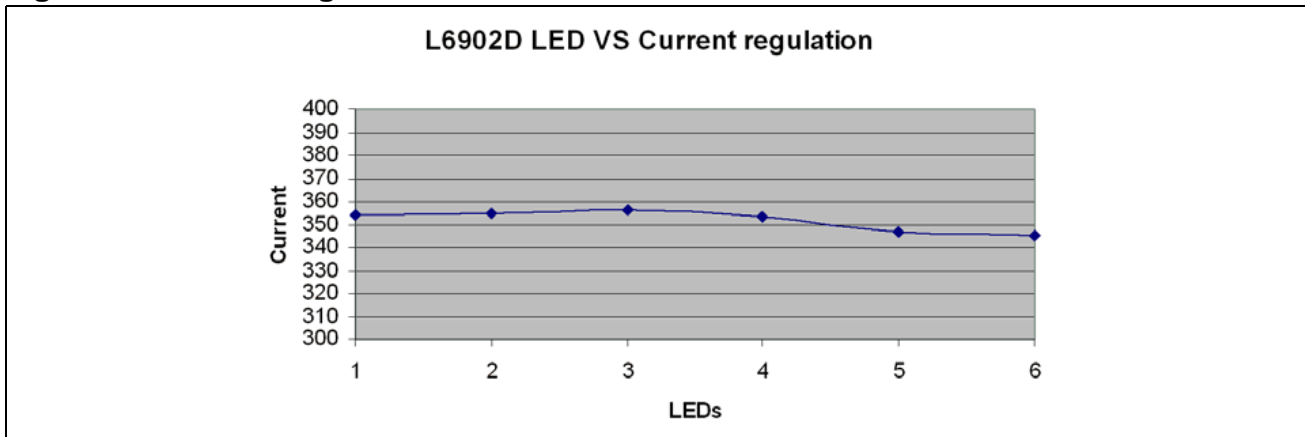
The current regulation from 1 to 6 LEDs or 3.3V to 19.5V is ± 1.5%.

Figure 18. Efficiency at 25V input:
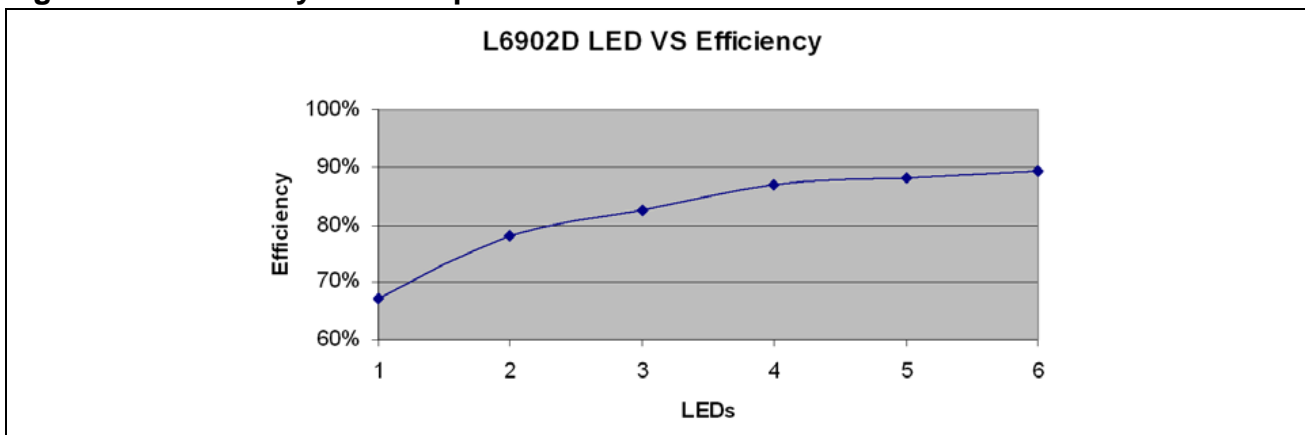
The efficiency ranges from 80% to 90% for 2 LEDs or more.

Figure 19. Ripple current

Peak to peak output ripple current is less than 7% of the output current.

5 CONCLUSION:

This application note has shown three reference designs to drive LEDs in constant current mode. One is a boost, to drive a flashlight at a higher voltage than the input. The others are two buck topology to drive string in series for a various number of LEDs.

Table 6. Revision History

Date	Revision	Description of Changes
June 2004	1	First Issue

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