

Application Note 5310

Introduction

This paper describes the various methods of driving the high power and high brightness LED. The task of designing an LED based system involves the following selection.

- I. number of LED used and the connection scheme between LEDs
- II. linear or switch mode LED driver
- III. power supply source i.e. DC voltage or AC mains or battery
- IV. optical subsystem, e.g. lens, filter cover etc.

The number of LED needed depends on the luminance required and the current the LEDs are driven.

The optical subsystem is not covered here as it is beyond the scope of this paper.

LED connection scheme

If there is more than one LED, the LED connection scheme must be decided.

There is no hard and fast rule in selecting the connection scheme. Sometimes it is a matter of preference. In some cases, the LED drivers chosen will decide the connection scheme. At times, the available power supply and efficiency required may influence the connection scheme.

Typically, the connection between LED is classified into three main configurations.

a) Series

b) Parallel

This is subdivided into

- i) Common anode
- ii) Common cathode
- iii) Common anode and common cathode

c) Mixed series – parallel

- i) Series of two LEDs
- II) Series of 'n' LEDs

Series connection

Figure 1 shows the series connection. The LED current in the series is the same throughout the series. Its disadvantage is that if one LED is opened, no LED will light up. The total VF across the series LED is higher, but the current requirement is lower.

The LED driver circuit used must be capable of producing output LED voltage greater than the series total VF. Generally, the closer the rated LED output voltage to the series LED total VF, the better is the efficiency.

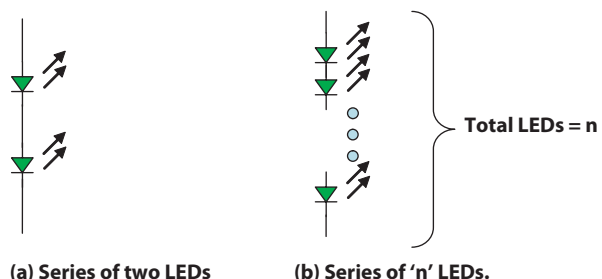


Figure 1. Series connection

Common anode or common cathode parallel connection

The common anode or common cathode parallel connection is used if each individual LED current is set independently. The advantage of this connection is that if one LED is opened, the other LEDs are unaffected. The disadvantage of this connection is that a higher current rating is needed.

Common anode and common cathode parallel connection

The difference between the LED forward voltages will cause current hogging. In cases where this is unavoidable, use the smallest number of LEDs with matched electrical, thermal and operating lifetime characteristic. The matched LEDs are equivalent to a single larger LED with a higher current rating. However, the matched LEDs may drift apart due to different degradation and thermal characteristics.

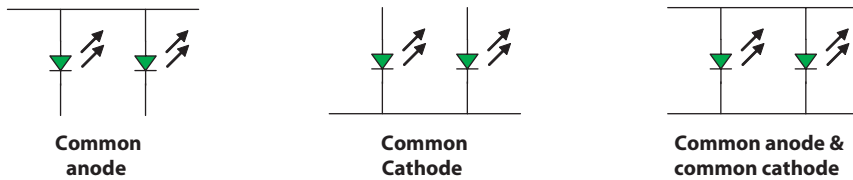


Figure 2. Parallel connection example

Mixed series – parallel connection

Figure 3 shows some examples of mixed series – parallel connection. This is usually selected as a trade off between the total V_F and the total current required, so that it will fit with available led drivers.

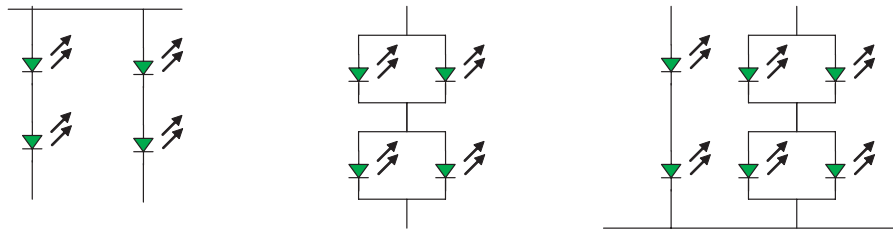


Figure 3. Mixed series – parallel connection example

LED drivers

The connection scheme will influence the number of drivers channel needed.

Most LED driver typically has a single channel. However, there are some multi channel LED drivers available. Each channel can drive only a single series connected LEDs or a single branch of the parallel connected LED in common anode or common cathode configuration. The following condition must be met to be able to drive the series connected LEDs.

- Output LED driver voltage must be greater than the total V_F of the series connected LED
- LED driver constant current output must be higher or equal to the desired LED current.
If the current is higher, use PWM dimming or modify the circuit, for example the sense resistor.

In general, LED drivers are classified into:

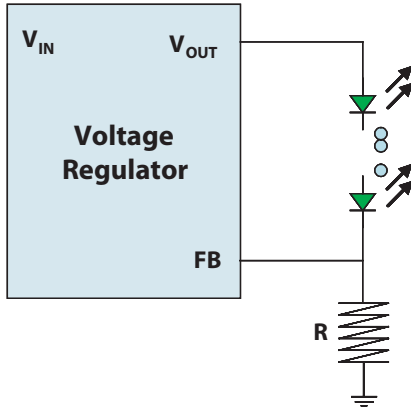
- Linear LED driver
- Switch mode LED driver

Linear LED driver are less efficient and generally occupy a larger space. Switch mode LED driver is more efficient and generally smaller. However, they have electrical and radiated noise and are complicated to design.

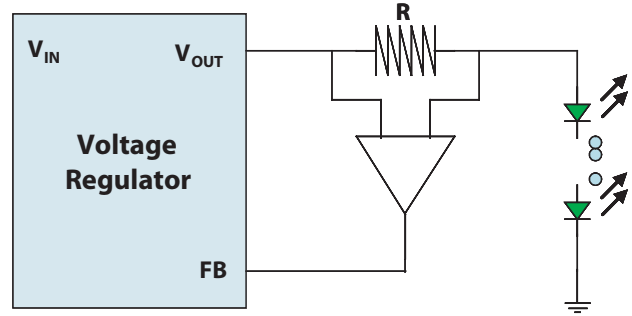
When the input power supply is lower than the LEDs total V_F , switch mode LED driver must be used. The selection between linear or switch mode is generally decided by simplicity, the available power supply and efficiency.

Converting a voltage regulator to LED driver

A typical voltage regulator has the following pins, V_{IN} , GND, V_{OUT} and FB. The FB pin sense a voltage to control the voltage regulator output voltage. For a constant current LED driver, current sense is necessary. By placing a resistor in the LED current path, the LED current is converted to a sense voltage at the FB pin. The resistor is usually placed at the LED cathode side for low side current sensing. Alternatively, the resistor is placed on the LED anode side for high side current sensing. A differential amplifier with high common mode rejection ratio is needed to sense the voltage across the resistor.



(a) Low side current sensing



(b) High side current sensing

Figure 4. Converting a voltage regulator to LED driver

The resistor value for low side current sensing is $\frac{V_{FB}}{I_{LED}}$

However, for high side current sensing, the resistor value required is $\frac{V_{FB}}{I_{LED} \times A_V}$

Note:

V_{FB} is the regulated feedback voltage at the FB pin.

I_{LED} is the desired LED current.

A_V is the gain of the differential amplifier.

For linear LED driver, the number of LEDs that can be driven in series is $N = \frac{V_{IN} - V_{DO} - V_R}{V_F}$

For the switch mode LED driver, the number of LEDs is $N = \frac{V_{OR} - V_R}{V_F}$

Note:

V_{IN} is the input voltage supply.

V_{DO} is the drop out voltage.

V_R is the sense voltage across the resistor.

V_{OR} is the rated designed output voltage of the series connected LED string.

V_F is the typical forward voltage of a single LED.

Linear LED driver examples

1. Simple resistive current limiting.

A resistor is used to limit the LED current from a DC power supply.

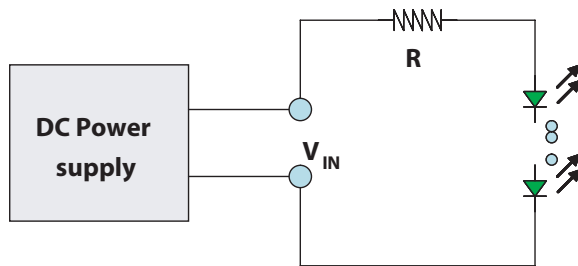


Figure 5. Resistor as a current limiter

The resistance is given by $R = \frac{V_{IN} - V_F}{I_F}$

Notes:

V_F - total VF of the series connected LED string.

I_F - desired LED current.

V_{IN} - input voltage supply.

The advantage of simple resistive limiting is the simplicity. However, the LED current is not stable due to LED forward voltage drift.

2. LM317 or LM317HV

Figure 6 showed the LM317HV voltage regulator used as an LED driver.

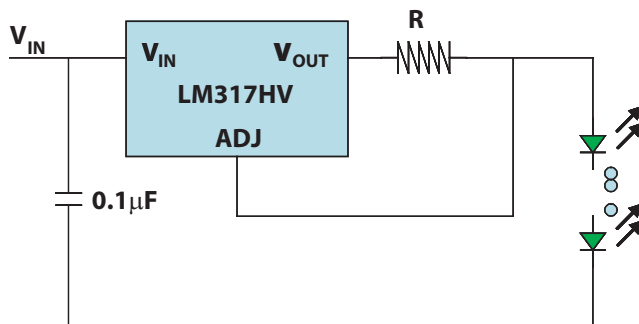


Figure 6. LM317HV LED driver

The LM317HV regulates a fixed 1.23 V between the ADJ and the OUT pin.

The LED current is given by the equation, $I_{LED} = \frac{1.23}{R}$

The advantage of this circuit over the simple resistive driver is that the LED current is constant despite the LED forward voltage drift.

3. LM2941

Another driver similar to the LM317 is the LM2941. The LM2941 voltage regulator has a maximum input voltage of 26 V. The LM2941 regulates 1.275 V across the ADJ and GND terminal. Figure 7 show the LM2941 as an LED driver providing 354 mA.

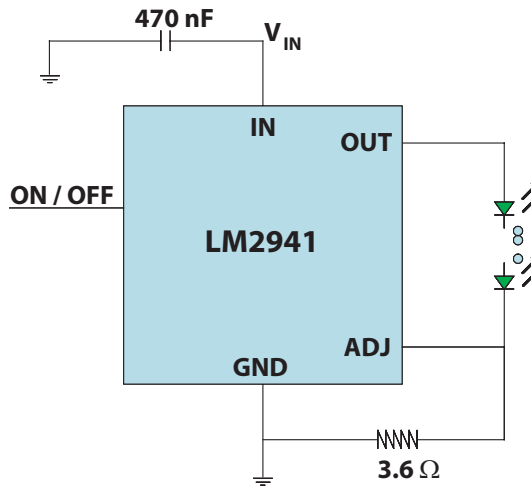


Figure 7. LM2941 LED driver

4. LT3021

The LT3021 is another linear voltage regulator with maximum input voltage at 10 V and a maximum current rating of 500 mA. The LT3021 regulates the output to maintain 0.2 V across the ADJ and GND terminal.

The LED current is $\frac{0.2}{R}$. The dropout voltage is 160 mV.

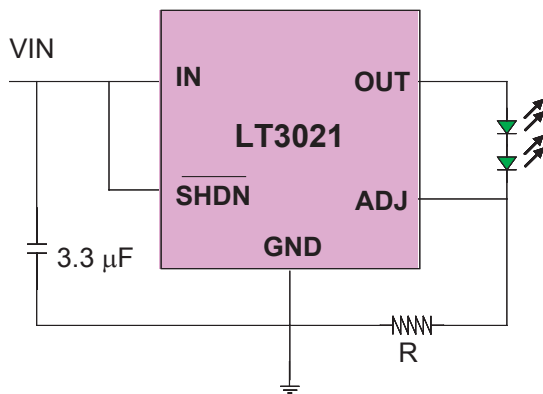


Figure 8. LT3021 LED driver

If the LED V_f is 3.6 V, the number of series connected LED is two.

5. TLE4242G

V_{REF} is regulated to 177 mV between ADJ and GND pins.

The maximum input voltage rating is 42 V with a dropout voltage of 0.7 V.

The LED current in the circuit is $\frac{V_{REF}}{R}$

In the circuit shown in Figure 9, $R = 5.1 \Omega$. The LED current is 347 mA.

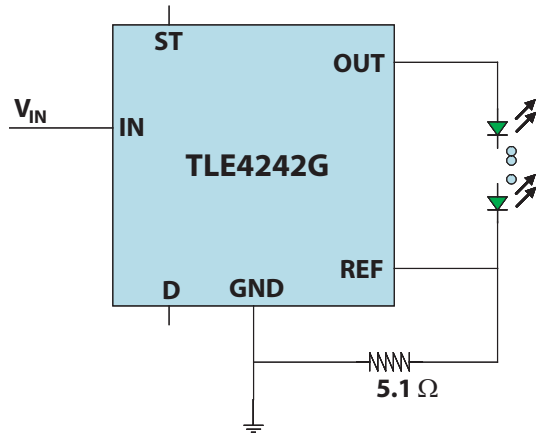


Figure 9. Infineon TLE4242G LED driver

6. AS3691 and AS3692

The AS3691 has a voltage rating of 15 V with maximum LED current of 400 mA.

The AS3692 is similar to AS3691. The difference is the AS3692 has a voltage rating up to 50 V, but the maximum current is 200 mA.

Contact Austriamicrosystem for latest information on availability and application notes on AS3691 and AS3692.

7. MAX16800 LED driver

This LED driver has a voltage rating of 40 V. The driver regulates a fixed voltage across the CS+ and CS-

The current is set by an external resistor, $R_S = \frac{V_{SENSE}}{I_{LED}}$

Notes:

I_{LED} is the desired LED current

V_{SENSE} is typically 0.204 V across CS+ and CS- pins.

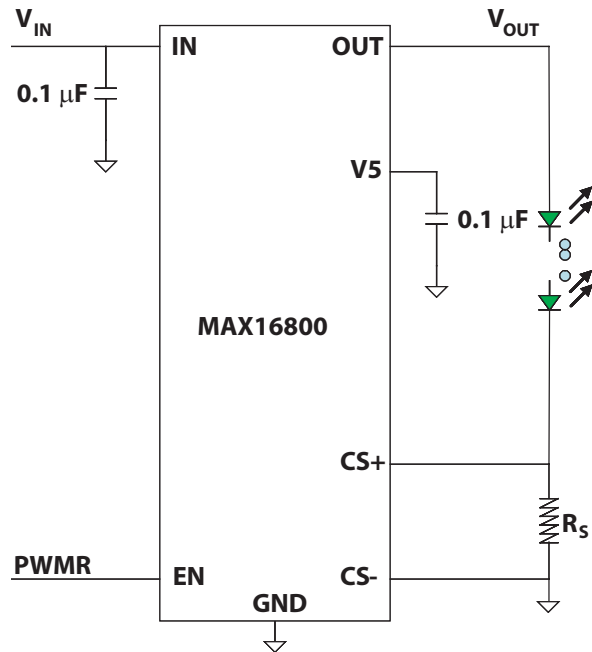


Figure 10. Maxim 16800 LED driver

For LED color management application with the ADJD-J823 and the HDJD-J822, the PWM output from the ADJD-J823/ HDJD-J822 is connected to the EN input of the MAX16800.

Switch mode LED driver

The switch mode LED driver is related to the switching voltage regulator topologies. The switching voltage regulator maintains a constant voltage at various current loads. The switch mode LED driver however, deliver constant current to LED at whatever VF the LEDs required, provided that the over voltage protection or power rating is not exceeded.

Some common examples of switch mode LED driver topologies are:

- a) BUCK. These are step down regulators; the output voltage is generally lower than the input voltage.
- b) BOOST. These are step up regulators; the output voltage is higher than the input.
- c) BUCK-BOOST. These are step down/step up regulators; the output voltage is inverted.
- d) SEPIC. This is similar to buck boost except the output voltage is not inverted.
- e) FLYBACK. These are step up or step down regulators with a transformer instead of an inductor.

Designers should obtain information on the IC datasheets and application notes from the manufacturer and work closely with the LED driver manufacturer.

Before turning on a switch mode LED driver, the LEDs should be connected. An open circuit in the switch mode LED will cause the output voltage to rise to maximum limit and may exceed the LED driver maximum voltage rating.

Switch mode LED driver examples

1. HV9911 in boost topology

The input voltage (21-27 V) is provided between VIN and GND. This boost topology circuit provides 80 V maximum output voltage. I.e. the number of InGaN LEDs that can be driven is 12 to 20 LEDs. If the PWM is not used, it should be connected to VDD to enable the LED driver.

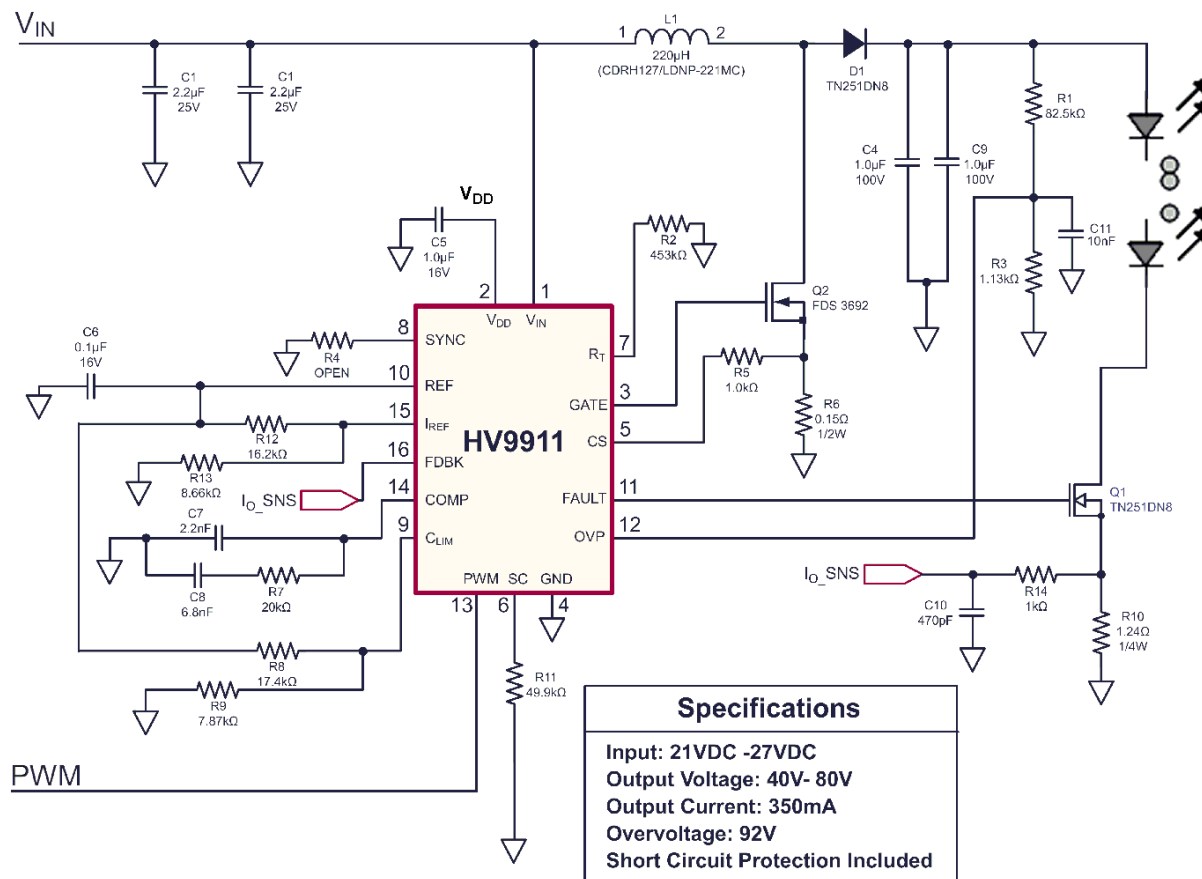


Figure 11. HV9911 in boost topology

The LED current is related to the equation, $V_{REF} \times \left(\frac{R_{13}}{R_{12} + R_{13}} \right) = I_{LED} \times R_1$

Notes:

1. V_{REF} is typically 1.25 V.
2. The maximum LED current for this circuit is 350 mA.

2. HV9911 in buck topology

This buck topology circuit accepts 130 to 200 V DC input between VIN and GND. It can provide a 20 to 100 V LED output voltage. The high side current sensing limits the LED current to 350 mA. If the PWM is not used, it should be connected to VDD to enable the LED driver.

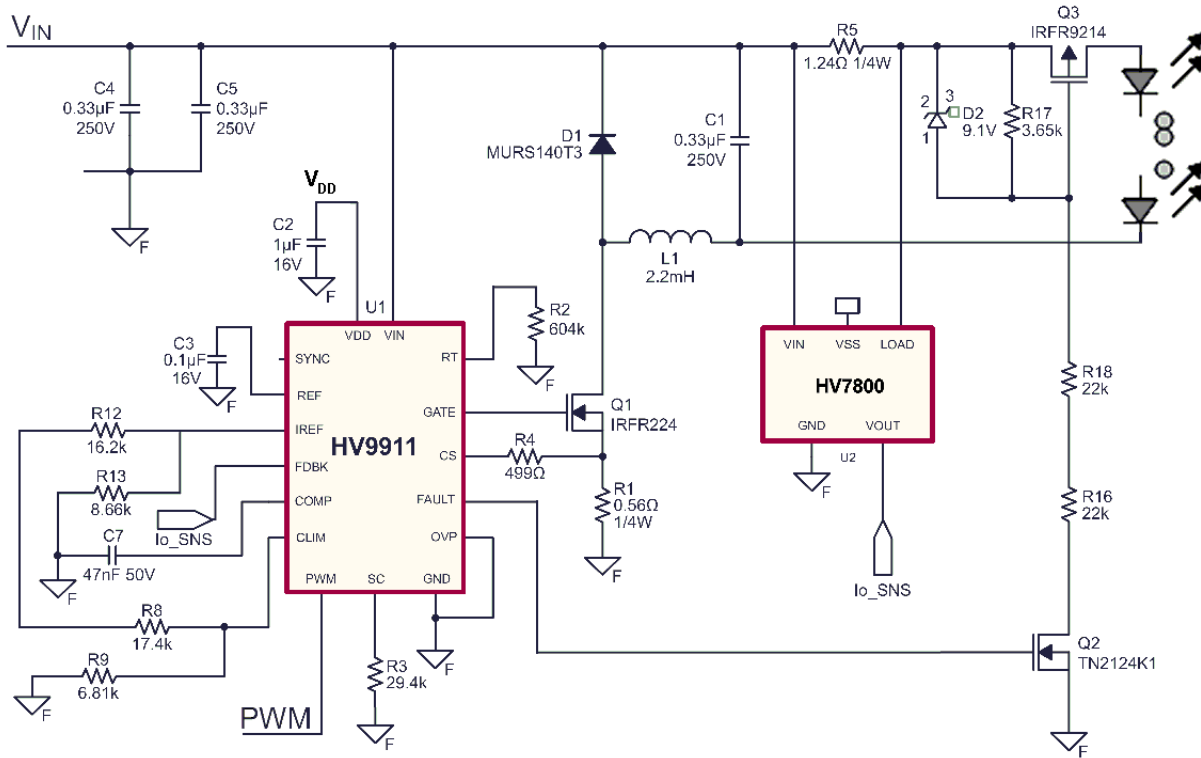


Figure 12. HV9911 in buck topology

The LED current is related to the equation, $V_{REF} \times \left(\frac{R_{13}}{R_{12} + R_{13}} \right) = I_{LED} \times R_1$

Notes:

1. V_{REF} is typically 1.25 V.
2. The maximum LED current for this circuit is 350 mA.

3. HV9910

This buck topology circuit is not isolated from line voltage. The LEDs must be connected to the driver before turning on the AC supply.

Table 1 shows the possible VAC input range with this circuit. The components L1 and R4 values are selected based on the operating LED current. Assuming that the LED forward voltage is 3.6 V, the maximum number of LED that can be driven is approximately eleven.

Table 1. Component selection.

VAC Input range	VAC Input setting	L1	L1 Part *	R4 Ω	LED current mA	Output LED driver voltage	
						min	max
90-265 V	110 VAC	4.7 mH, 0.4 A	PCH-45-475	0.56	50-350	10	40
90-265 V	250 VAC	4.7 mH, 0.4 A	PCH-45-475	0.56	50-350	20	40
90-135 V	110 VAC	1.0 mH, 2 A	PCV-2-105-02	0.135**	350-1500	10	40

Notes:

* The inductor part numbers are from Coilcraft.

** Implemented by two 0.27 Ω resistors connected in parallel.

The components values for row 1 and 2 are shown in Figure 13.

The control PWM signal must be isolated from mains. If the PWM is not used, it should be connected to VDD to enable the LED driver. If any measuring instrument needs to be used, they must also be isolated using isolating transformer.

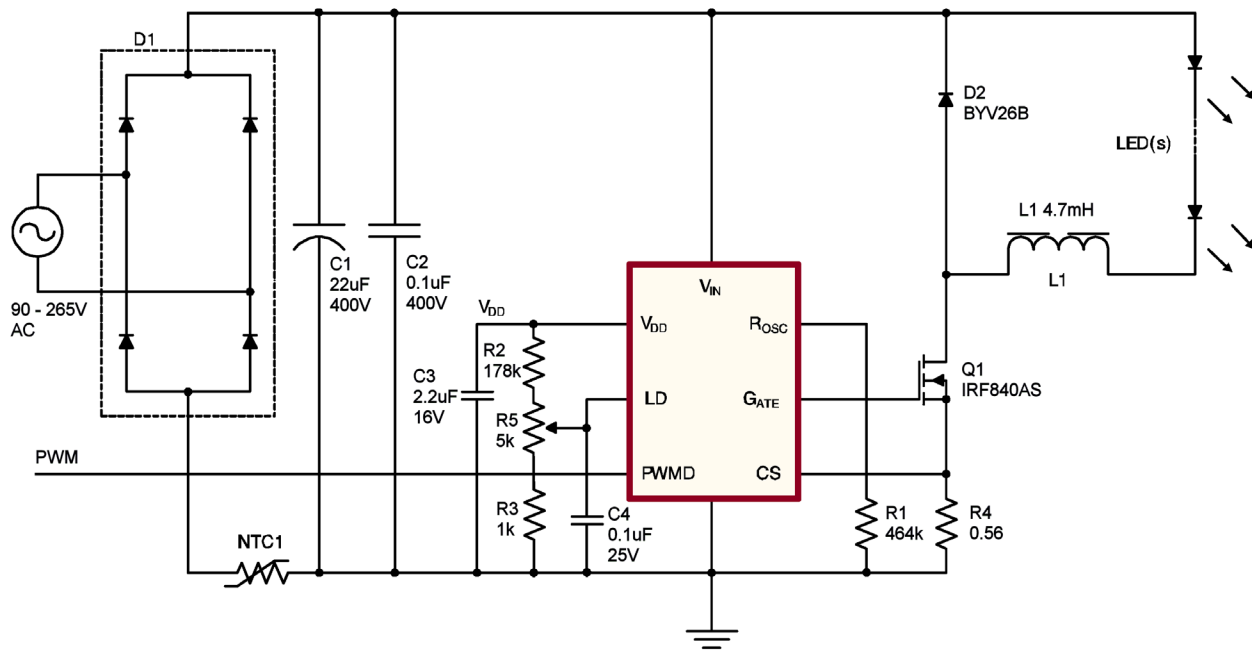


Figure 13. HV9910 in buck topology

4. ST L6902

This is a buck LED driver. Table 2 shows the various components values needed to obtain the corresponding LED current.

Table 2. Resistor selection

R1	R3	R4	R5	R6	Rs	LED current
9.1 k Ω	510 Ω	1 k Ω	8.2 k Ω	27 k Ω	0.33 Ω	350 mA
9.1 k Ω	510 Ω	910 Ω	2.4 k Ω	20 k Ω	0.2 Ω	700 mA

Note: The component values for the first row are shown in figure 15 to provide 350 mA LED current.

The Vdim pad provides an input for linear dimming or inverted logic PWM dimming. At 0 V, the LED current is maximum. As the voltage increase from 0 V to 3.3 V, the LED current will reduce linearly from maximum to zero.

Resistor R1 and R3 provide over voltage protection at 23.3 V in case an open circuit occur at the LED output. Assuming InGaN LEDs with $V_F = 3.6$ V, the maximum number of LEDs that can be connected in series is six InGaN LEDs.

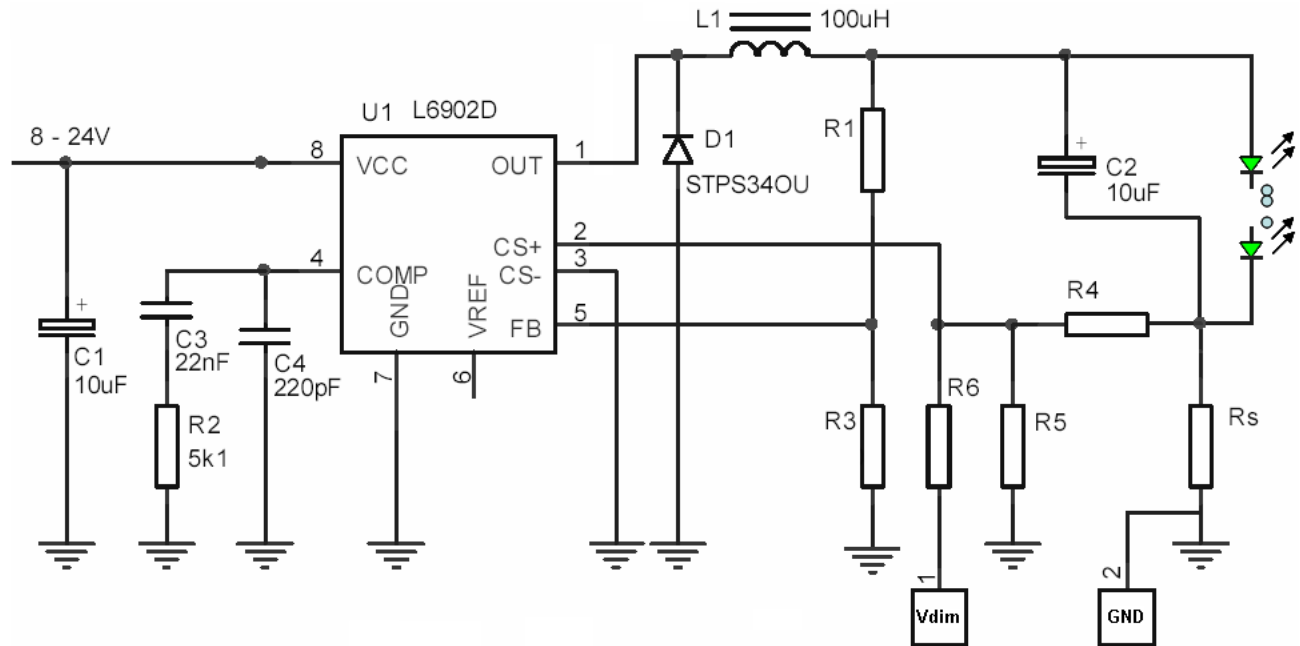


Figure 14. L6902D LED driver

5. ST L4973

This is a buck topology LED driver with 48 V input. A maximum of 12 InGaN LEDs can be connected. Resistors R1, R2 and the internal 5.1 V supply reduced the sense voltage to 0.5 V.

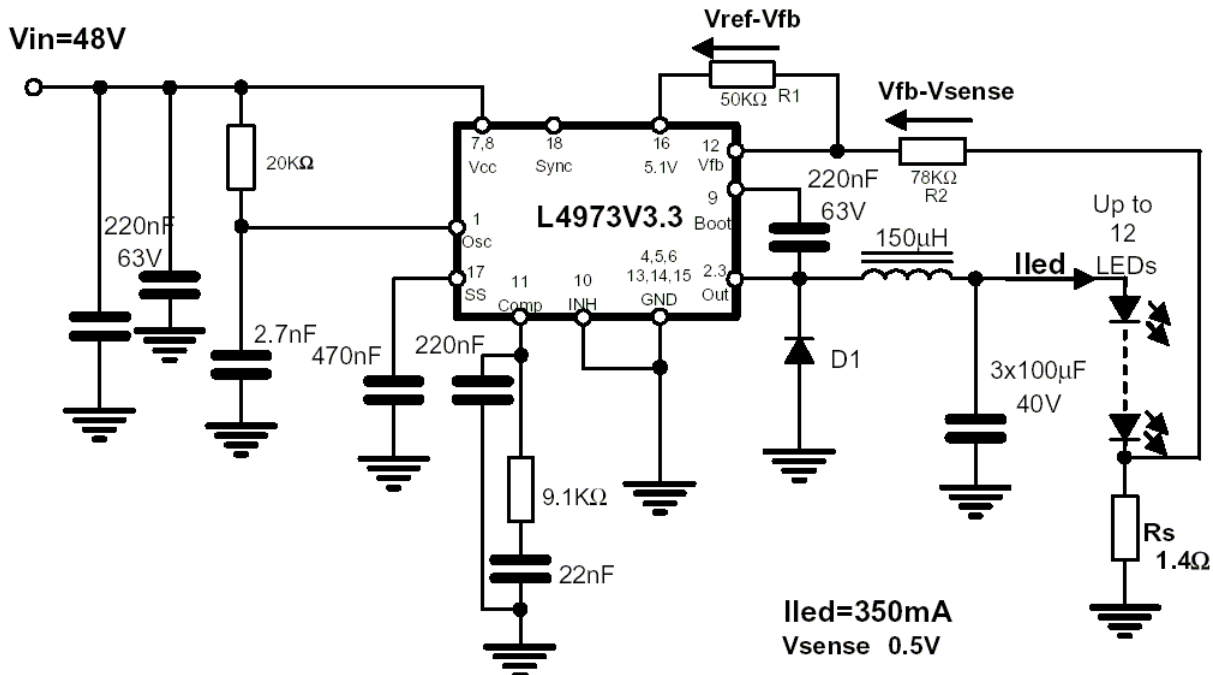


Figure 15. L4973V3.3 LED driver

6. LTC3490

This circuit is able to drive one InGaN LED from a single battery cell. An internal sense resistor limits the LED output current to 350 mA. If the LED pin is open, the output voltage is internally limited to 4.7 V.

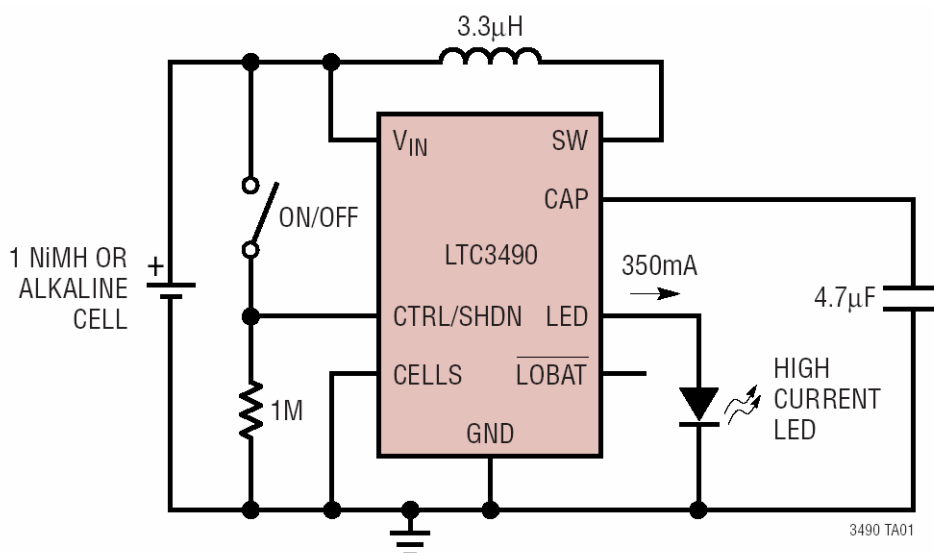


Figure 16. LTC3490 driving a single LED

7. LTC3783

This flyback LED driver can provide 150 mA to a series connected LEDs. The over voltage protection is trigger at 130 V and deactivate at 120 V. The number of series LEDs that can be connected is $120/3.6 = 33$ LEDs. PWM signal provide the dimming control.

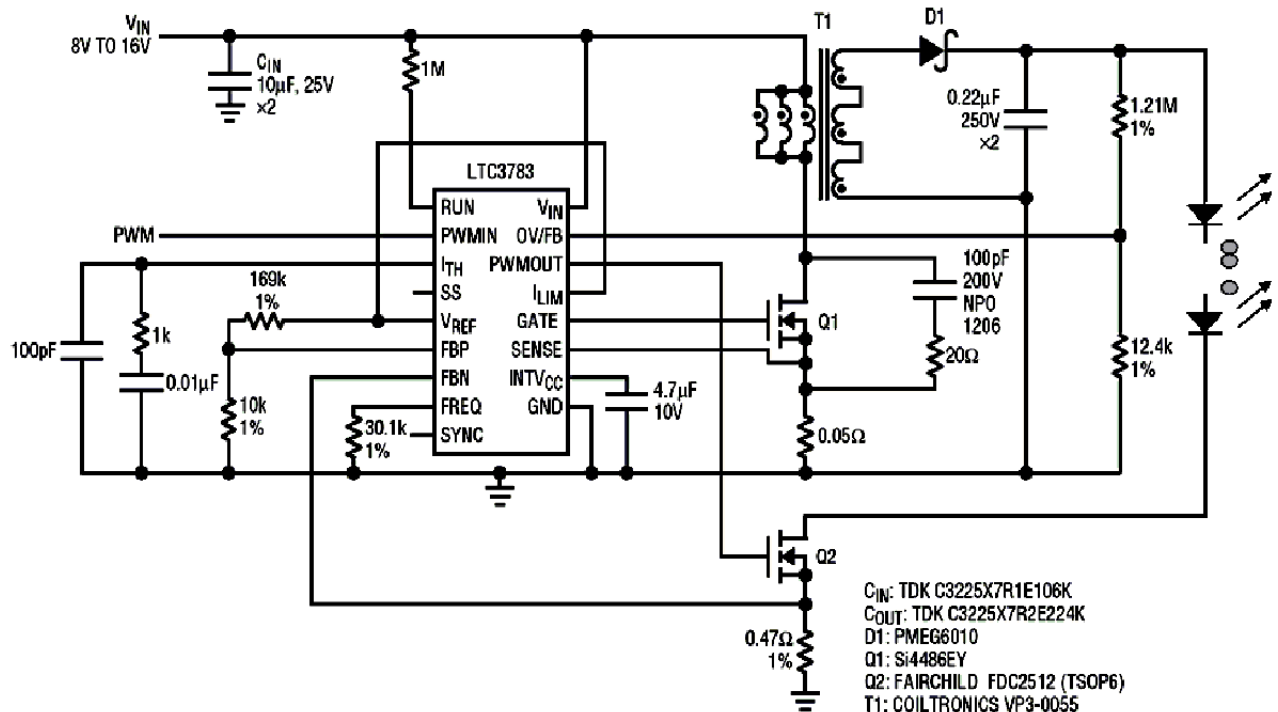


Figure 17. LTC3783 LED driver

8. LM3402

This is a step down buck LED driver. It has a constant on time architecture and the circuit is designed for a single INGAN LED. Refer to the web site below for other LM3402 reference design for other LED output voltage.
<http://www.national.com/webench/ledrefdesigns.do>

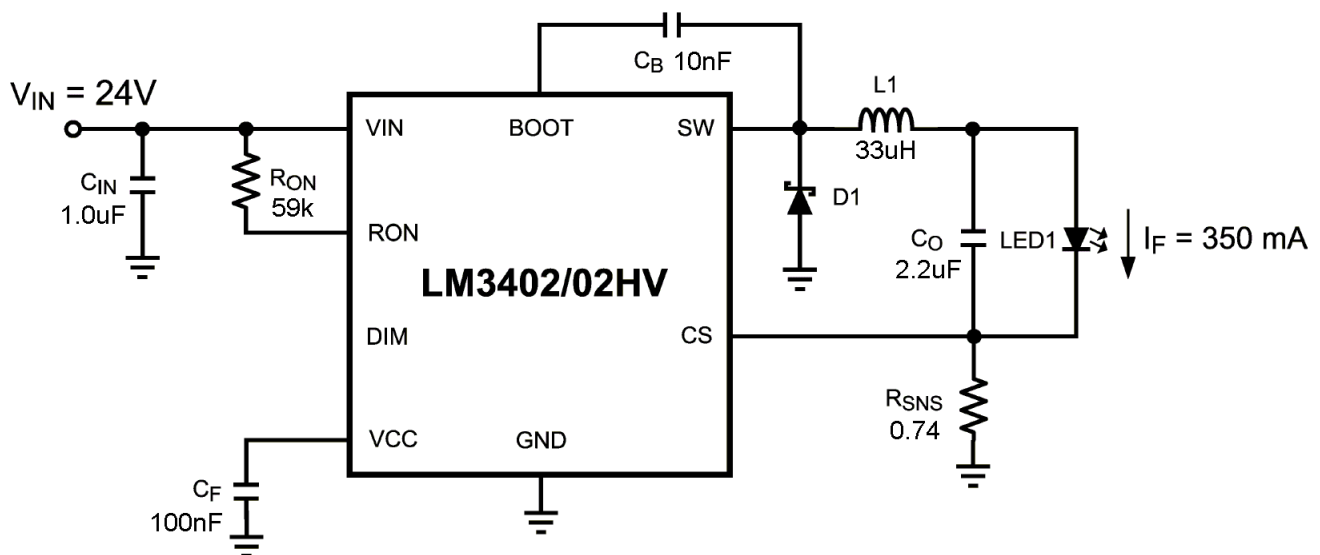


Figure 18. LM3402 LED driver

Table 3 shows the component changes needed to drive ten LEDs in a series.

Table 3. Component changes required for different operating LED current

LED color	Total VF range	LED current	RON	L1	L1 part	Rsns
Red	25 to 35 V	300 mA	340 k Ω	330 μ H	SLF10145T-331MR54	0.68 Ω
Green or Blue	30 to 45 V	150 mA	499 k Ω	330 μ H	SLF7045T-331MR25	1.33 Ω

Note: The inductor parts are from TDK.

9. Maxim 5035

This buck topology circuit accepts V_{in} from 7.5 V to 30 V. The LED current is 350 mA. The rated LED output voltage is 12 V. One to three InGaN LEDs can be driven.

$V_{CONTROL}$ is a linear dimming input and the LED current is given by the equation below.

$$I_{LED} = \frac{V_{REF} \times (R1 + R5) - V_{CONTROL} \times R1}{R5 \times R_{SENSE}}$$

Notes:

R_{SENSE} is the parallel equivalent of R2, R3 and R4.

V_{REF} is typically 1.22 V.

$V_{CONTROL}$ is the external linear dimming voltage, 0 V for maximum LED current.

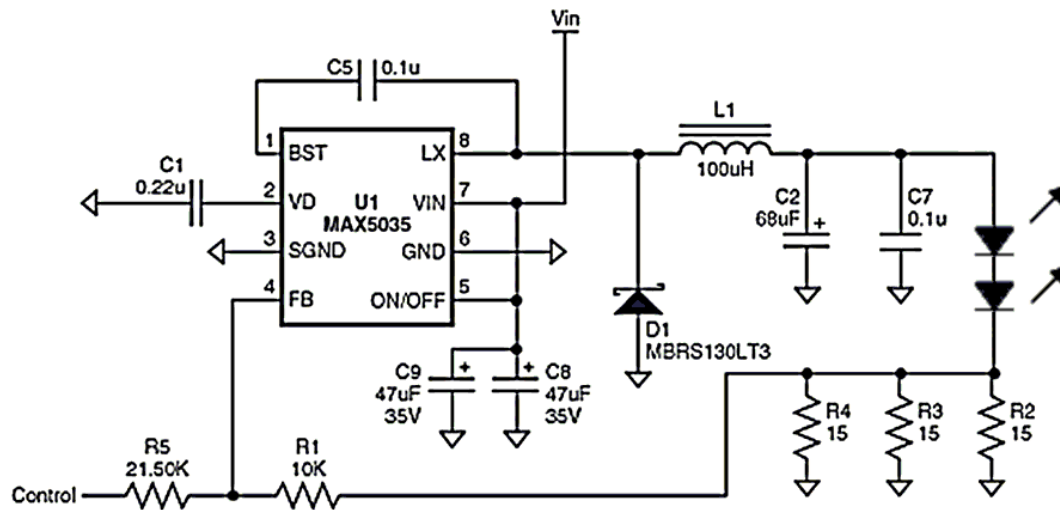


Figure 19. Maxim MAX5035 LED driver

10. MAX16801 / MAX16802

The MAX 16801 is suitable for rectified 85 VAC to 265 VAC applications.

The MAX16802 is suitable for low input DC input voltage.

An example of the MAX16802 driver is shown in Figure 21.

This circuit is design for driving a single InGaN LED at 350 mA.

For other configuration, refer to AN3639, under design procedure.

The DC input voltage is from 10.8 to 24 V. Resistor, R1 and R2 clamped the output voltage to 29 V.

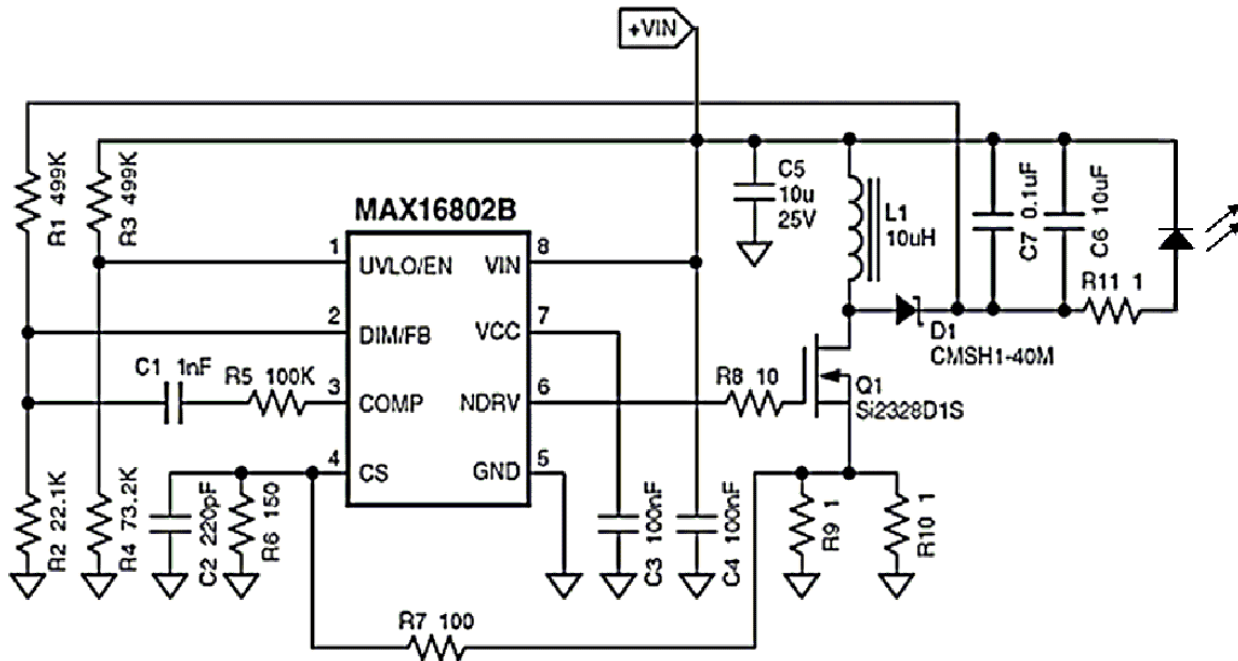


Figure 20. MAX16802B LED driver

Reference

1. AND8109/D LED constant current scheme. Theory of operation.
<http://www.onsemi.com/pub/Collateral/AND8109-D.PDF>
2. Datasheets: LM317HV, LM2941, LT3021, TLE4242G, MAX16800, HV9911, HV9910, L6902D, L4973, LTC4930, LTC3783, LM3402, MAX5035, MAX16801/MAX16802.
3. AS3691, AS3692 product brief.
http://www.austriamicrosystems.com/03products/products_detail/AS3691/download/AS3691_Features.pdf
4. HV9911DB1v2 High brightness boost LED driver with 1:3000 dimming ratio and excellent current regulation.
http://www.supertex.com/feature_hv9911.html
5. HV9911DB3 High brightness step-down LED driver with excellent current regulation.
http://www.supertex.com/feature_hv9911.html
6. AN-H55 Boost Converter LED Drivers using Supertex's HV9911.
http://www.supertex.com/feature_hv9911.html
7. HV9910DB1 Off-line high brightness LED driver board.
http://www.supertex.com/feature_hv9910.html
8. HV9910DB2v2 Universal voltage off-line high brightness LED driver demo board.
http://www.supertex.com/feature_hv9910.html
9. AN-H48 Buck-based LED Drivers using the HV9910/HV9910B.
http://www.supertex.com/feature_hv9910.html
10. AN2129 Dimming of super high brightness LEDs with L6902.
<http://www.st.com/stonline/products/literature/an/11247.pdf>
11. AN1891 Driving LEDs using L497X, L597X, L692X DC-DC converters families. <http://www.st.com/stonline/products/literature/an/10232.pdf>
12. High Voltage Boost/LED Controller Provides 3000:1 PWM Dimming Ratio. Linear Technology Magazine March 2006. <http://www.linear.com/pc/downloadDocument.do?navId=H0,C1,C1003,C1042,C1031,C1115,P15692,D14232>
13. Maxim AN3668 High-Efficiency Current Drive for High-Brightness LEDs.
<http://pdfserv.maxim-ic.com/en/an/AN3668.pdf>
14. Maxim AN3639 Design of a Nonisolated, Flyback LED Driver Circuit.
<http://pdfserv.maxim-ic.com/en/an/AN3639.pdf>
15. How to use switching regulators in driving high brightness LEDs By Chris Richardson.
<http://www.mobilehandsetdesignline.com/howto/183702675> or
<http://www.powermanagementdesignline.com/news/183701658>

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AV02-0532EN - July 21, 2010

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