深圳市明和科技有限公司

DN81
Lighting handbook

Introduction

Light Emitting Diodes (LEDs) are becoming more and more popular in general illumination. They offer benefits in energy efficiency, long life and ruggedness. LEDs are low voltage devices and both safe and easy to use.

However, LEDs are 'current driven' devices and simply applying a voltage to drive them is not a good method of control. Current control schemes are essential to maintain constant brightness. Additionally, LEDs offer longevity which means that they can often work in excess of 50,000 hours. LED drivers play a key role in achieving maximum working life. In particular, switching regulators maximize electrical and thermal efficiency.

Zetex provides a comprehensive range of high brightness LED drivers to suit a wide range of applications. These high efficiency drivers meet all these stringent requirements.. In this handbook, a broad range of design notes are included for customers to select the right device and application circuits. Test results and bill of materials are also included to provide a convenient means to achieve optimum solutions.

Individual datasheets for all the devices mentioned in these these devices can be found on **www.zetex.com.** All the designs have been built and evaluated. However, users should satisfy themselves of the suitability for their specific application.

ZETEX SEMICONDUCTORS

Table of contents, ordered by application

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DN61

Dual cell powered ZXSC310 solution for a 1W high power white LED

Khagendra Thapa, Principal Systems Engineer, Zetex Semiconductors

Description

High power LEDs are increasingly being used in lighting applications (general illumination, portable, signage/security, traffic, automotive, architectural) as lumens, and efficacy of high power LEDs are increasing while the cost per lumens is decreasing.

Low cost, small and simple solutions are important in applications such as flashlight, signage and illuminations where 1W high power LED is powered from a low voltage supply as in single and dual cell batteries.

Figure 1 shows a typical simple low cost solution with a ZXSC310 driving a 1W LED with a typical forward voltage of 3.4V at 300mA from a dual cell battery. A dual cell supply will have a voltage range of 1.8V to 2.5V for NiCd and NiMH type batteries and up to 3V for alkaline type batteries. The component values are tabulated (see Tables 1 and 2), depending on the range of voltage which is defined by the battery chemistry.

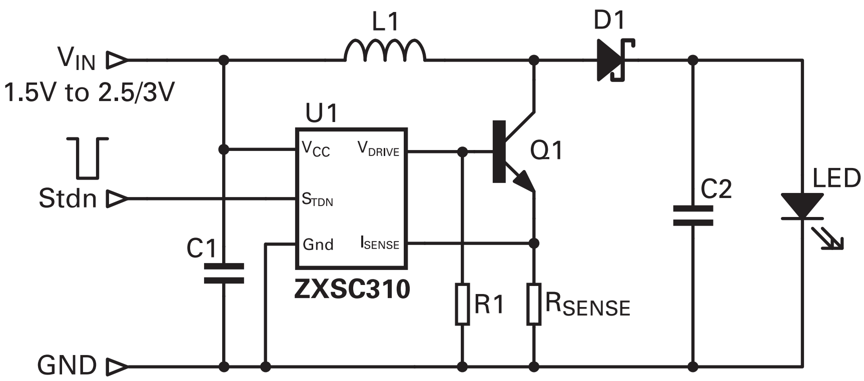


Figure 1 Typical dual cell battery powered 1W LED drive circuit

ZXSC310 is a constant current boost converter in a small SOT23-5 package. It has a typical drive current of 2.3mA at 1.8V. The drive current at 25°C is 1.5mA minimum at 1.5V supply.

The bipolar transistor switch, Q1, should have adequate voltage and peak switching current ratings, a very high transistor gain (h_{fe}), a very low saturation voltage (V_{CE}) and a small device package size with an adequate thermal capability. The transistor, Q1 in this application, is a low saturation voltage transistor, ZXTN25012EFL, with a very high gain of 700 at 1A collector current at 25°C to match the drive current from the Drive pin of the ZXSC310.

Note: If transistors with lower gain are used, then at lower temperatures, it may not support a full switching current and therefore proper operation may not start or may take few seconds to start.

The Schottky diode should have an adequate peak switching current rating and a very low forward voltage. The Zetex ZXSC1000 Schottky diode, SD1, has a low forward voltage. If operation at higher temperature is required then the low leakage, low forward voltage, Zetex ZLLS1000 can be used.

The choice of inductor, L1, depends on the desired switching frequency, the LED current, the input voltage, forward voltage of the Schottky diode, SD1, and the LED forward voltage.

Note: The LED current output is dependent on the input voltage, the LED forward voltage, the sense resistor and the inductor value.

Dual cell NiCd/NiMH battery solution

A dual cell NiCd/NiMH battery voltage range is 1.8V to 2.5V. Table 1 shows the component values for a dual cell NICd/NiMH battery powered ZXSC310 solution for a 1W high power white LED. The efficiency and the LED current versus the input voltage performance are shown in Figures 2 and 3.

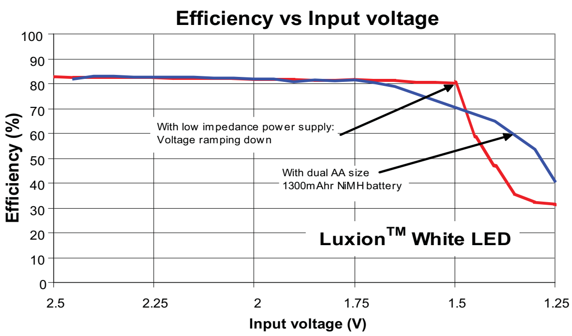


Figure 2 Efficency vs. input supply voltage

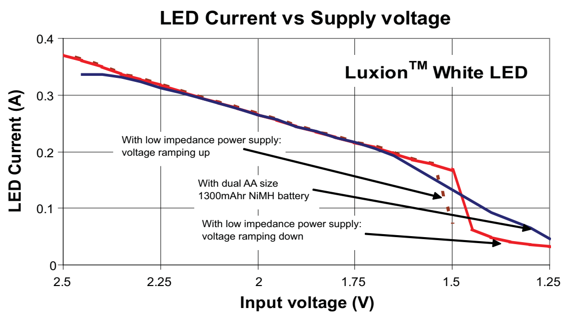


Figure 3 LED current vs. input supply voltage

Reference	Part no.	Value	Manufacturer	Contact details
U1	ZXSC310E5	LED driver	Zetex	www.zetex.com
Q1	ZXTN25012EFH	high gain, low $V_{CE(sat)}$	Zetex	www.zetex.com
SD1	ZHCS1000 or ZLLS1000	low forward voltage V_F	Zetex	www.zetex.com
L1	DO3316P-103	10µH, 2A	Coilcraft	www.coilcraft.com
R_{SENSE}	Generic	33mΩ	Generic	NA
R1	Generic	10kΩ	Generic	NA
C1	Generic	1µF, 6.3V, X7R	Generic	NA
C2	Generic	6.8µF, 6.3V	Generic	NA
LED1	LXHL-NW98	White LED; 3.4V	Lumileds	www.lumileds.com

Table 1 Bill of materials for dual cell NiCd/NiMH battery powered single 1W LED driver

Dual cell alkaline battery solution

The dual cell alkaline battery has a voltage range of up to 3V. Table 2 shows the component values for a dual cell alkaline battery powered ZXSC310 solution for a 1W high power white LED. The efficiency and the LED current versus the input voltage performance are shown in Figures 4 and 5.

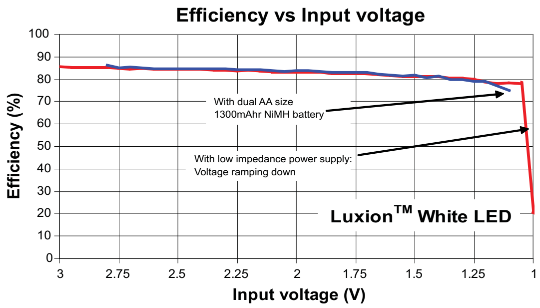


Figure 4 Efficiency vs. input signal voltage

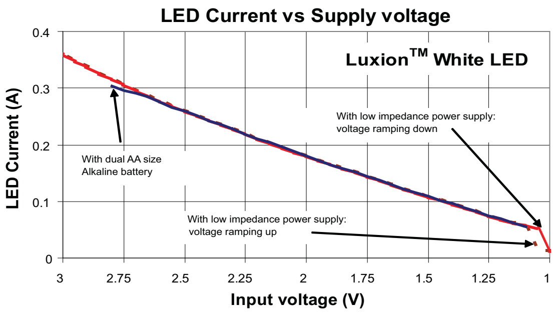


Figure 5 LED current vs. input supply voltage

Reference	Part no.	Value	Manufacturer	Contact details
U1	ZXSC310E5	LED driver	Zetex	www.zetex.com
Q1	ZXTN25012EFL	high gain, low $V_{CE(sat)}$	Zetex	www.zetex.com
SD1	ZHCS1000 or ZLLS1000	low forward voltage V_F	Zetex	www.zetex.com
L1	DO3316P-103	10uH, 2A	Coilcraft	www.coilcraft.com
R_{SENSE}	Generic	50mΩ	Generic	NA
R1	Generic	10kΩ	Generic	NA
C1	Generic	1μF, 6.3V, X7R	Generic	NA
C2	Generic	6.8μF, 6.3V	Generic	NA
LED1	LXHL-NW98	White LED	Lumileds	www.lumileds.com

Table 2 Bill of materials for dual cell alkaline battery powered 1W LED driver

Dimming and shutdown

In Figure 1, the shutdown pin, Stdn, can be tied to V_{CC} pin for normal operation. If the shutdown pin is taken to ground, the ZXSC310 enters standby mode with a low quiescent current of 5μA. The shutdown pin can also be used for PWM dimming by connecting a PWM signal. The LED current is then dependent on PWM duty ratio.

Thermal management

The LED junction temperature should be maintained within the specified maximum or de-derating curve, whichever is lower, by use of proper thermal management for lumens maintenance and LED protection. Size 0805 for the sense resistor is adequate.

Boot-strap operation

In boot-strap mode, the supply to the V_{CC} is from the output stage (cathode of SD1) to maintain the supply to the ZXSC310 at a reasonably constant voltage even when the battery voltage reduces. This improves the ZXSC310 drive pin current capability due to the reasonably constant voltage of 3.4V typical (or the forward voltage of the LED) at the V_{CC} pin, even though the battery voltage may drop below 1.5V.

The boot-strap allows the ZXSC310 to continue driving the LED even with battery supply drops below 0.8V after the initial successful start-up. The boot-strap mode is recommended for a single cell alkaline/NiMH/NiCd battery. The boot-strap mode can also be used in throw-away (single use) dual cell alkaline batteries to draw as much energy as possible before discarding the battery. Figures 6 and 7 show the efficiency and LED current versus battery voltage for a boot-strap mode of operation with an AA size dual cell alkaline battery.

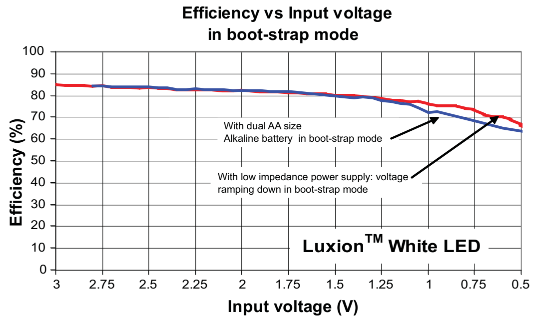


Figure 6 Efficiency vs. input supply voltage

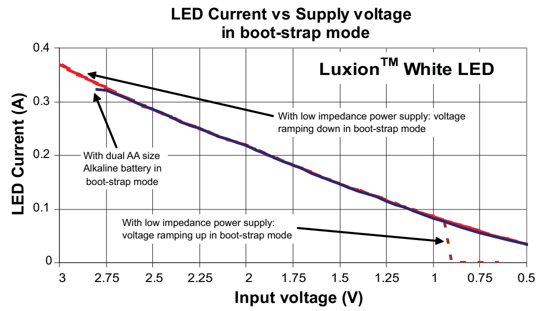


Figure 7 LED current vs. input supply voltage

Note: To prevent rechargeable batteries entering a deep discharge state, ZXSC310 devices can be shut down (by pulling the shutdown pin low to the ground) by an external circuit when the rechargeable battery voltage falls below its recommended minimum voltage. The boot-strap mode is not recommended with a ZXSC310 for dual/three cell NiCd/NiMH rechargeable batteries without a under voltage protection.

DN62

ZXSC310 Solution to drive 3 LEDs connected in series

Description

This solution is optimized for an input voltage range of 4.3V to 3V. The LED current is set to 15mA V_{IN} = 4.3V and 8mA at V_{IN} = 3V.

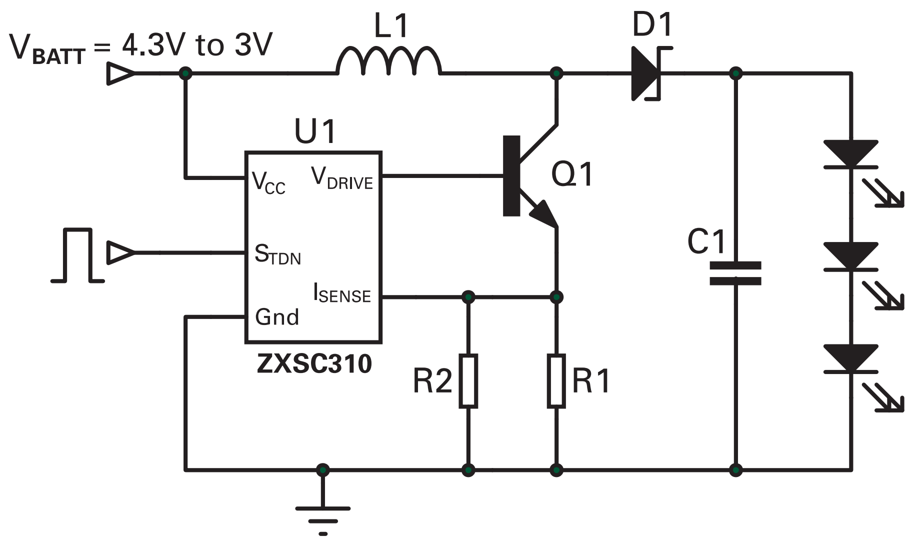
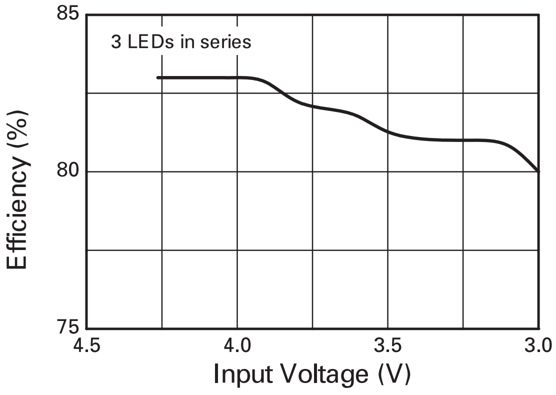
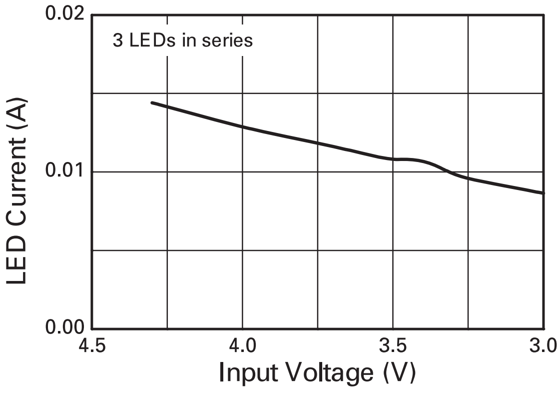


Figure 1 Schematic diagram



Input Voltage v Efficiency



Input Voltage v LED Current

Figure 2 Performance graphs

Reference	Part no.	Value	Manufacturer	Contact details
U1	ZXSC310E5	NA	Zetex	www.zetex.com
Q1	FMMT618	NA	Zetex	www.zetex.com
D1	ZHCS1000	1A	Zetex	www.zetex.com
R1	Generic	510mΩ	Generic	NA
R2	Generic	510μF	Generic	NA
C1	Generic	2.2μF	Generic	NA
L1	DO1608P-103	10μH	Coilcraft	www.coilcraft.com
LED1-3	NSPMW500BS	White LED	Nichia	www.nichia.com

Table 1 Bill of materials

DN63
ZXSC310 Solution to drive 8 LEDs connected in series

Khagendra Thapa, Principal Systems Engineer, Zetex Semiconductors

Description

Low cost, small simple and low power multi-LED drive solutions are important in applications including LCD backlight, key illuminations and effects for handheld devices (e.g. cell phones), signage and indicators. The LED current is generally between 10mA to 30mA and is powered from a single cell Li-Ion or three cell alkaline/NiMH/NiCad batteries. For battery powered applications low shutdown quiescent current is important to conserve battery life.

Figure 1 shows a simple low cost boost convertor, ZXSC310, driving eight series connected LEDs. ZXSC310 is in a small SOT23-5 package. The design solution is for an application with an input voltage range of 4.5V to 2.5V (e.g. a single cell Li-Ion can have a voltage range of 4.3V to 2.6V) with LED current optimized at 20mA typical, at 4.0V supply. The LED current at 4V is chosen to match the 20mA typical forward current of the LED used.

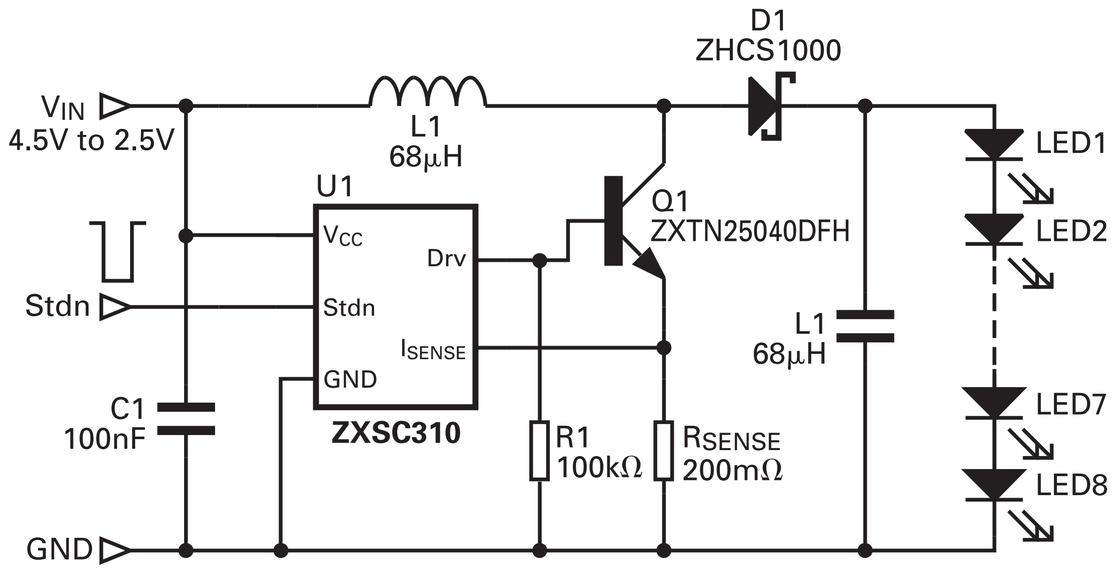


Figure 1 Schematic diagram

With a single cell Li-Ion battery, the circuit in Figure 1 can drive 3 or more series connected LEDs, the maximum number of LEDs limited by the breakdown voltage of the bipolar transistor Q1. Depending on the number of LEDs connected in series, the sense resistor, R_{SENSE}, will have to be adjusted to obtain the required LED current at a certain supply voltage.

The ZXSC310 can be shutdown by pulling the Stdn pin low. The quiescent current in the shutdown mode is typically 5µA. If shutdown feature is not required tie the Stdn pin to the V_{CC} pin.

Figure 2 shows the efficiency and the LED current against supply voltage. The LED current decreases with the supply voltage. This helps to draw less current from a discharged battery.

The bill of materials for the circuit in Figure 1 is shown in Table 1.

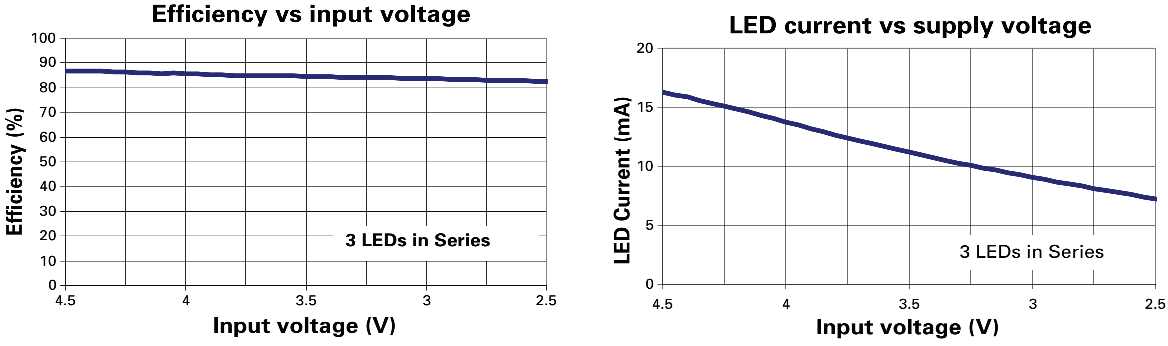


Figure 2 Performance graphs

Ref.	Part no.	Value	Manufacturer	Contact details
U1	ZXSC310E5	NA	Zetex	www.zetex.com
Q1	ZXTN25040DFH	NPN, V_{CEO} = 40V	Zetex	www.zetex.com
D1	ZHCS1000	1A, low forward voltage V_F	Zetex	www.zetex.com
R_{SENSE}	Generic	200mΩ	Generic	NA
R1	Generic	100kΩ	Generic	NA
C1	Generic	100nF, 6.3V, X7R	Generic	NA
C2	Generic	2.2μF, 35V	Generic	NA
L1	DO1608P-683	68μH	Coilcraft	www.coilcraft.com
LED1-8	NSPMW500BS	White LED	Nichia	www.nichia.com

Table 1 Bill of materials

DN64
ZXSC310 Solution flashlight

Description

A solution is provided for flashlight driving 4 white LEDs connected in series from a 2 alkaline cell input.

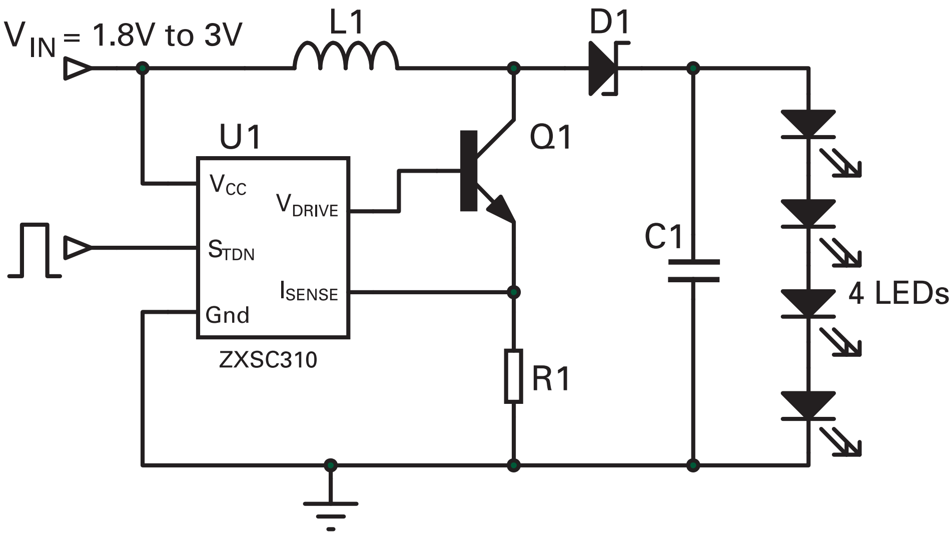


Figure 1 Schematic diagram

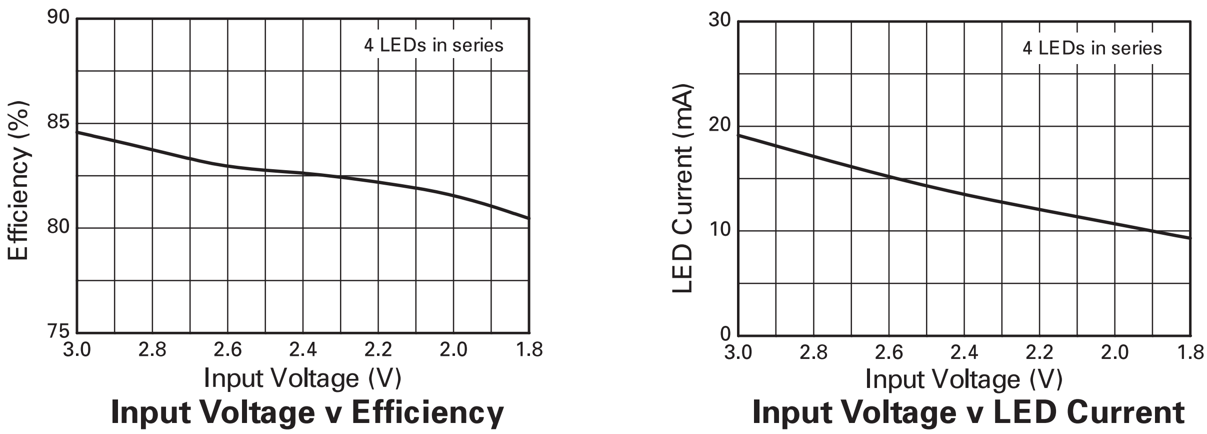


Figure 2 Performance graphs

Reference	Part no.	Value	Manufacturer	Contact details
U1	ZXSC310E5	LED driver	Zetex	www.zetex.com
Q1	FMMT618	2.5A, low $V_{CE(sat)}$	Zetex	www.zetex.com
D1	ZHCS1000	1A, low V_F	Zetex	www.zetex.com
L1	LPO2506OB-683	68µH, 0.4A	Coilcraft	www.coilcraft.com
R1	Generic	130mΩ	Generic	NA
C1	Generic	2.2µF	Generic	NA
LED1	Learn-4753A	White LED	LG Innotek	www.iginnotek.com

Table 1 Bill of materials

DN65
ZXSC310 Solution for emergency light

Description

This solution is provided for an emergency light driving 8 white LEDs connected in series from a 4 cell input.

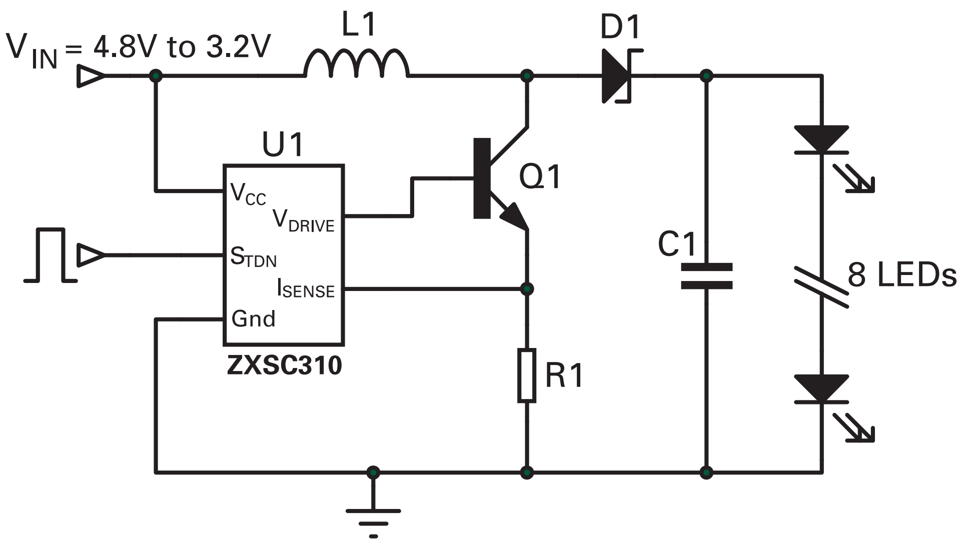


Figure 1 Schematic diagram

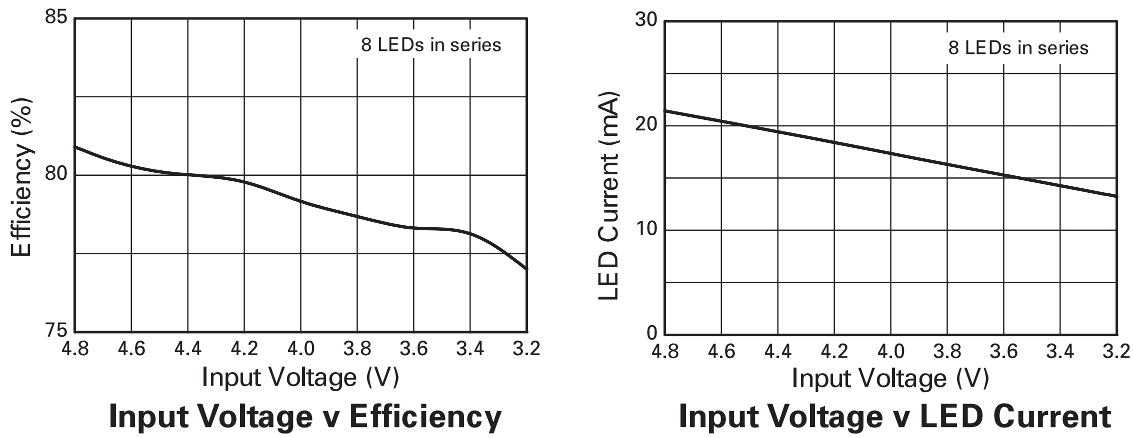


Figure 2 Performance graphs

Reference	Part no.	Value	Manufacturer	Contact details
U1	ZXSC310E5	LED driver	Zetex	www.zetex.com
Q1	FMMT619	2A, low $V_{CE(sat)}$	Zetex	www.zetex.com
D1	ZHCS1000	1A, low V_F	Zetex	www.zetex.com
L1	LPO2506OB-683	68µH, 0.4A	Coilcraft	www.coilcraft.com
R1	Generic	82mΩ	Generic	NA
C1	Generic	2.2µF	Generic	NA
LED1	NSPW500BS	White LED	Nichia	www.nichia.com

Table 1 Bill of matrials

SEMICONDUCTORS

DN66
An OLED bias supply for a clamshell handset sub display

Author - Kit Latham, Applications Engineer, Zetex Semiconductors

Description

Portable applications such as cell phones are becoming increasingly complex with more and more features designed into every generation. One popular feature is to replace the STN sub display with an OLED sub display. OLED displays have infinite contrast ratio and are self-illuminating. This gives the handset manufacturer two key advantages, the first is lower power consumption and the second is a slimmer display. One disadvantage with OLED sub displays over LCD sub displays is the higher leakage current when not in use, which is the majority of the time. The way to overcome this issue is to disconnect the OLED sub display when the handset is dormant.

The ZXLB1600 is a boost converter that can provide the power requirements for OLED sub display with the additional feature of a fully integrated isolation switch which disconnects the input from output when the ZXLB1600 is shutdown, making it ideally suited to OLED biasing.

The schematic diagram in Figure 1 shows a full color OLED bias supply for clamshell handset sub display.

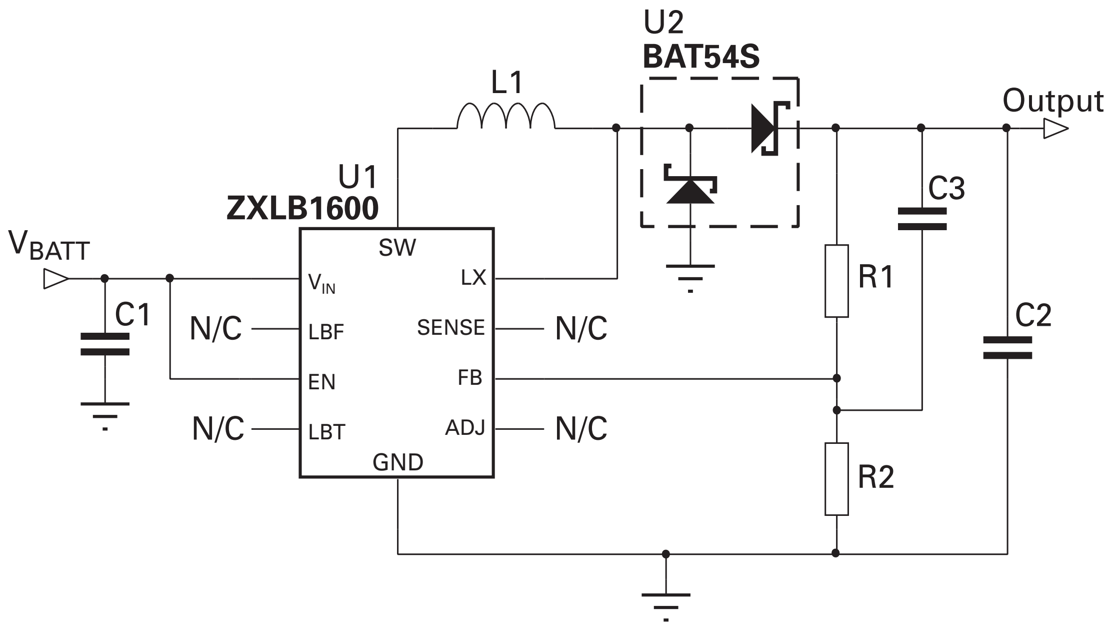


Figure 1 Schematic diagram

Note:
For applications where OLED leakage is not an issue and the ZXLB1600 isolation switch is not needed, the SW pin can be shorted to the V_{IN} pin, giving a further 3% to 5% improvement in efficiency.

The materials list and associated performance characteristics provide an OLED biasing solution for the following sub display specification:

- Input voltage: 4.2V to 3.0V
- Output voltage: 12V
- Output current: 20mA (max.)
- Output ripple: 50mVpk-pk (max.)

Reference	Value	Part number	Manufacturer	Contact details	Comments
U1		ZXLB1600X10	Zetex	www.zetex.com	OLED bias IC
U2		BAT54S	Zetex	www.zetex.com	Dual Schottky diode
L1	22μH	NPIS32Q220MTRF	NIC	www.niccomp.com	Low profile
R1	715kΩ	Generic	Generic	NA	0603 size
R2	82kΩ	Generic	Generic	NA	0603 size
C1	10μF/6V3	NMC0805X7R106M16	NIC	www.niccomp.com	0805 size
C2(1)	10μF/16V	NMC1206X7R106M16	NIC	www.niccomp.com	1206 size
C3	82pF/16V	NMC0603NPO820J50	NIC	www.niccomp.com	0603 size

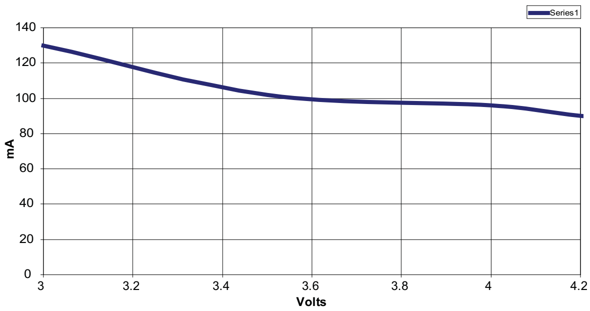
Table 1 Bill of materials

NOTES:

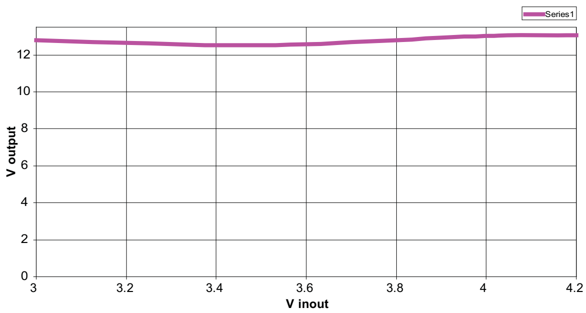
(1) For a lower profile, two 4.7μF 0805 capacitors can be used by connecting in parallel.

Typical operating characteristics

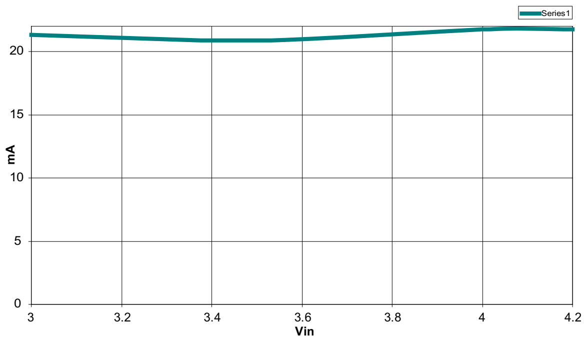
(For typical application circuit where V_{IN} = 3V, V_{OUT} = 12V, I_{OUT} = 20mA unless otherwise stated)



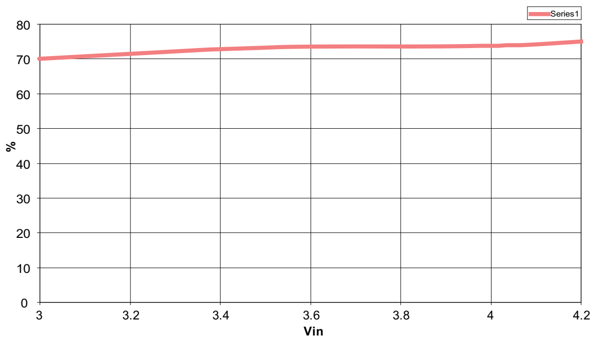
Input I v. input voltage



Output voltage v. input voltage



Output current v. input current voltage

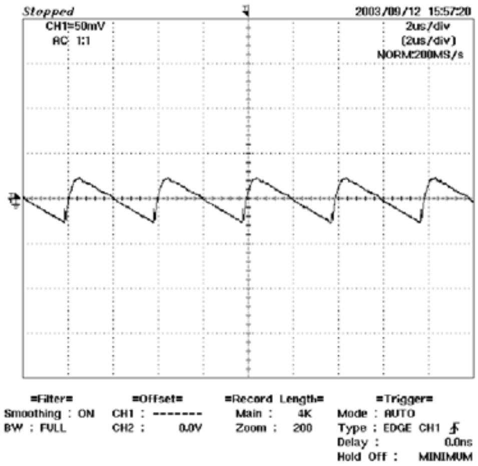


Efficiency v. input voltage

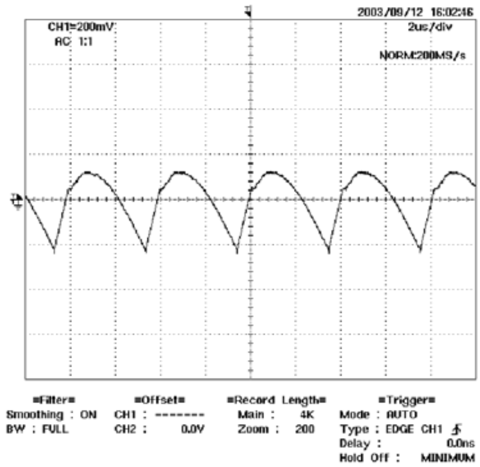
Figure 2 Performance graphs

Typical operating waveforms

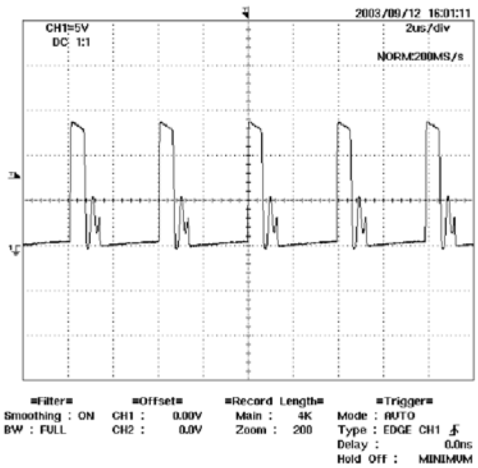
(For typical application circuit where V_{IN} = 3V, V_{OUT} = 12V, I_{OUT} = 20mA unless otherwise stated)



Output voltage ripple



Input voltage ripple

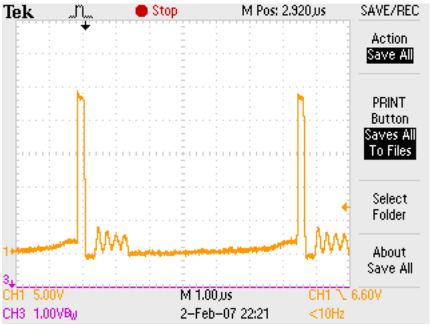


LX switching

Figure 3 Typical operating waveforms

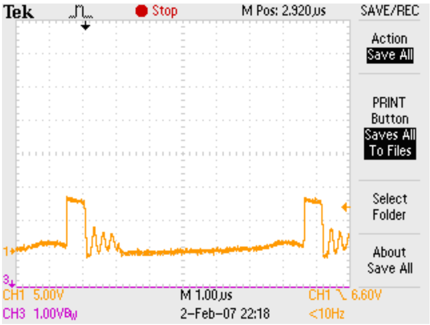
1.6V input with a 2mA load with a 25V DC output.

LX drive



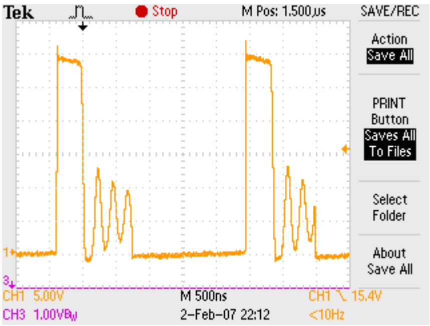
1.6V input with a 6mA load.

LX drive, output is now unregulated.



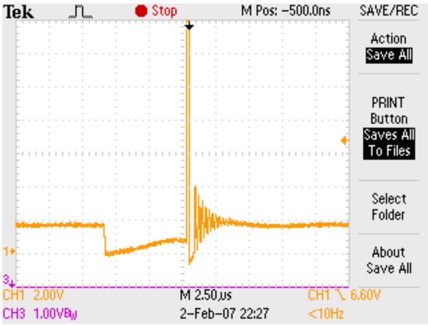
5.5V input with an 18mA load producing 28V DC output

LX drive



5.5V output with no load producing 28V output

This shows the fixed output LX drive waveform which can be as wide as 10µsec.



At 5.5V input and an output of 28V, this graph shows the typical output regulation to be <10% and ripple < 1V from no load to full load.

Additional notes

Adjusting output voltage

1) R1 and R2

When connected without external resistors R1 and R1, the ZXLB1600 will produce a nominal output voltage of 28V. This is because the chip has an internal high value resistor divider which is shunted by R1 and R2 externally if low value resistors are used.

The relationship between R1 and R2 and V_{OUT} is:

$$V_{OUT}(DC) = (R1+R2)/R1 \times 1.23V$$

The following table gives suggested E24/E96 resistor values for various output voltages.

Required output voltage	External resistor across R2	External resistor across R1
5V	280k	91k
12V	715k	82k
18V	1 M	75k
20V	1.15M	75k
22V	1.15M	68.1k
25V	1.2 M	62k

Table 2 Resistor values for output voltages

2) Output adjustment by external voltage

The internal voltage reference (Pin ADJ) may be overdriven by an external control voltage to set the output voltage. The relationship between applied voltage (V_{ADJ}) and output voltage (V_{OUT}) is:

$$V_{OUT} = 22.86 \times V_{ADJ}$$

Note that the output can be set to any value between the input voltage and the maximum operating voltage in this way. However, some non-linearity in the above expression may occur at values of V_{ADJ} below approximately 0.5V.

Also note that when driving the ADJ pin, the control voltage must have sufficiently low impedance to sink the bias current of the internal reference (10μA max).

3) PWM output adjustment

A Pulse Width Modulated (PWM) signal can be applied to the EN pin in order to adjust the output voltage to a value below the value set in 1) or 2). This method of adjustment permits the device to be turned on and the output voltage set by a single logic signal applied to the EN pin. No external resistors or capacitors are required and the amplitude of the control signal is not critical, providing it conforms to the limits defined in the electrical characteristics.

Two modes of adjustment are possible as described below:

Filtered 'DC' mode

If a PWM signal of 10kHz or higher is applied to the EN pin, the device will remain active when the EN pin is low. However, the input to the internal low pass filter will be switched alternately from V_{REF} to ground, with a duty cycle (D) corresponding to that of the PWM signal. This will present a filtered dc voltage equal to the duty cycle multiplied by V_{REF} to the control loop and will produce a dc output voltage lower than the maximum set value. This voltage is given by:

$$V_{OUT} = 28 \times D$$

A square wave signal applied to the EN pin, for example, will turn the device on and produce a nominal regulated output of 14V.

Gated mode

The ZXLB1600 contains a timing circuit that switches the device on a few microseconds after the application of a rising edge to EN and turns it back off again nominally 120µs after the falling edge of EN. So, if a lower frequency of 1kHz or less is applied to the EN pin, the device will be gated on and off at a duty cycle (D) corresponding to that of the input signal. The average output voltage is then given by:

$$V_{OUT}(avg) \sim 28 \times D$$

Output voltage can be adjusted all the way down to the input voltage by means of PWM control, but for best results, the duty cycle range should be kept within the specified range of 0.4 to 1. Lower duty cycles may result in increased output ripple and non-linearity in the relationship between duty cycle and output voltage. If a greater control range, or reduced ripple is required, the nominal output can be adjusted by one of the other methods before the PWM signal is applied.

Negative output

The ZXLB1600 can be used to provide a negative output voltage (in addition to the normal positive output) as shown in the application circuit below. In this circuit, the external resistors R3 an R4 are used to set the output voltage to 22V as described in the previous section. These resistors and output capacitor C2 have relatively low values in this circuit in order to give a short time constant. This improves the regulation of the negative voltage.

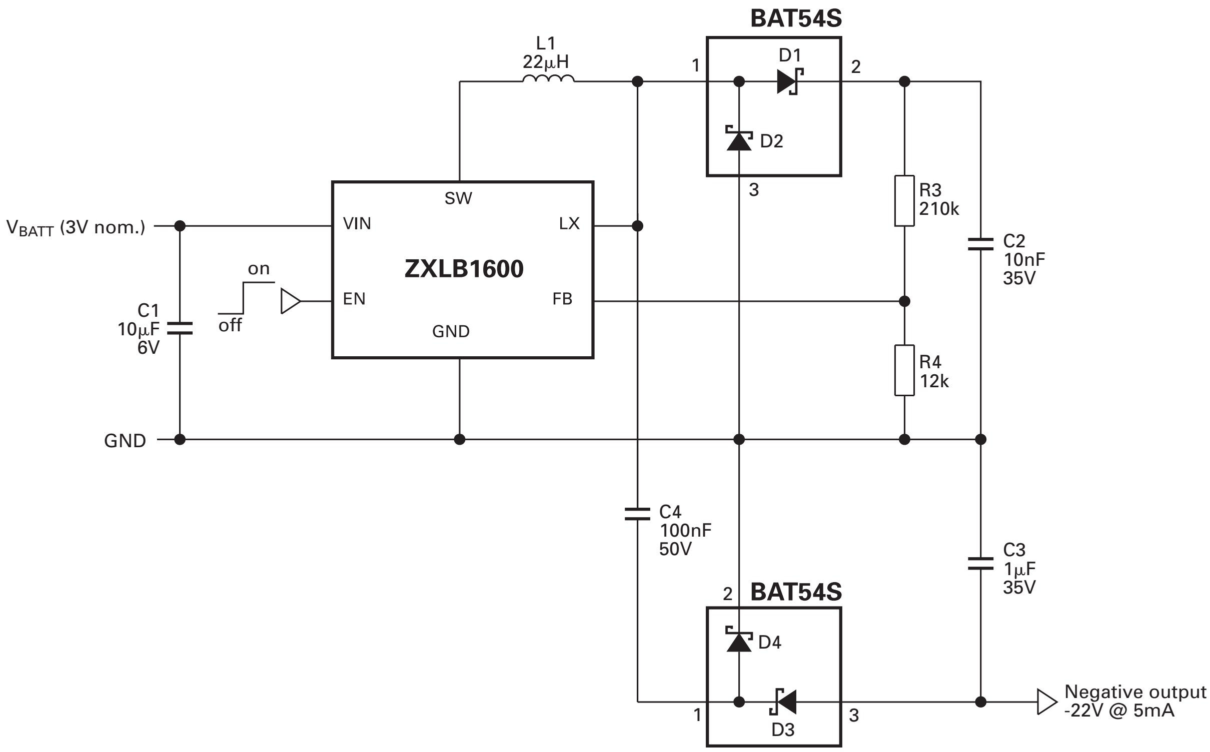


Figure 4 Title???????

Capacitor selection

A low ESR ceramic capacitor grounded close to the GND pin of the package is recommended at the output of the device. Surface mount types offer the best performance due to their lower inductance. A minimum value of 1μF is advised, although higher values will lower switching frequency and improve efficiency especially at lower load currents. A higher value will also minimize ripple when using the device to provide an adjustable dc output voltage.

A good quality, low ESR capacitor should also be used for input decoupling, as the ESR of this capacitor is effectively in series with the source impedance and lowers overall efficiency. This capacitor has to supply the relatively high peak current to the coil and smooth the current ripple on the input supply. A minimum value of 3.3μF is acceptable if the input source is close to the device, but higher values are recommended at lower input voltages, when the source impedance is high. The input capacitor should be mounted as close as possible to the IC.

For maximum stability over temperature, capacitors with X7R dielectric are recommended, as these have a much smaller temperature coefficient than other types.

Inductor selection

The choice of inductor will depend on available board space as well as required performance. Small value inductors have the advantage of smaller physical size and may offer lower series resistance and higher saturation current compared to larger values. A disadvantage of smaller inductors is that they result in higher frequency switching, which in turn causes reduced efficiency due to switch losses. Higher inductor values can provide better performance at lower supply voltages. However, if the inductance is too high, the output power will be limited by the internal oscillator, which will prevent the coil current from reaching its peak value. This condition will arise whenever the ramp time ILX(peak) x L/V_{IN} exceeds the preset 10μs maximum 'on' time limit for the LX output.

The ZXLB1600 has been optimized for use with inductor values in the range 10μH to 100μH. The typical characteristics show how efficiency and available output current vary with input voltage and inductance. The inductor should be mounted as close to the device as possible with low resistance connections to the LX and SW pins.

Suitable coils for use with the ZXLB1600 are those in the NPIS range listed from NIC components or LP02506 and DO1608 series, made by Coilcraft if preferred.

Diode selection

The rectifier diode (D1) should be a fast low capacitance switching type with low reverse leakage at the working voltage. It should also have a peak current rating above the peak coil current and a continuous current rating higher than the maximum output load current. Small Schottky diodes such as the BAT54 are suitable for use with the ZXLB1600 and this diode will give good all round performance over the output voltage and current range. At lower output voltages, a larger Schottky diode such as the ZHCS500 or MBR0540 will provide a smaller forward drop and higher efficiency. At higher output voltages, where forward drop is less important, a silicon switching diode such as the 1N4148 can be used, however this will give lower efficiency but will have better leakage characteristics than a Schottky device.

The BAT54S device specified in the application circuit contains a second diode (D2) as one half of a series connected pair. This second diode is used here to clamp possible negative excursions (due to coil ringing) from driving the drain of the output transistor below -0.5V. This prevents internal coupling effects, which might otherwise affect output regulation. The table below gives some typical characteristics for various diodes.

Diode	Forward voltage at 100mA (V)	Peak current (mA)	Continuous current (mA)	Reverse leakage (µA)
BAT54	530	300	200	2
ZHCS500	300	1000	500	15
MBR0540	390	1000	500	1
1N4148	950	450	200	0.025

Table 3 Typical diode characteristics

Increased efficiency

If isolation of the coil from the supply is not needed, the high side of this can be connected directly to V_{IN} to improve efficiency. This prevents power loss in the internal PMOS switch and typical efficiency gains of 5% can be achieved. (See efficiency vs. load curves). Some applications may require the coil to be fed from a separate supply with a different voltage to V_{IN}. In this case, the SW pin should be left floating.

Layout considerations

PCB tracks should be kept as short as possible to minimize ground bounce and the ground pin of the device should be soldered directly to the ground plane. It is particularly important to mount the coil and the input/output capacitors close to the device to minimize parasitic resistance and inductance, which will degrade efficiency and increase output ripple. The FB and LBT pins are high impedance inputs, so PCB track lengths to these should also be kept as short as possible to reduce noise pickup. Output ripple is typically only 50mV p-p, but a small feed-forward capacitor (~100pF) connected from the FB pin to the output may help to reduce this further. Capacitance from the FB pin to ground should be avoided, but a capacitor can be connected from the LBT pin to ground to reduce noise pickup into the low battery comparator if required.

Low Battery Detection Circuit (LBDC)

The device contains an independent low battery detection circuit that remains powered when the device is shutdown. The detection threshold is set internally to a default value of 1.98V, but can be adjusted by means of external resistors as described below.

Low Battery Threshold adjustment (LBT)

The internal potential divider network R3/R4 sets the detection threshold. This is accessible at the LBT pin and can be shunted by means of external resistors to set different nominal threshold voltages. The potential divider defines threshold voltage according to the relationship:

$$V_{LBT} = (R3+R4)/R4 \times 1.21V$$

When using external resistors, these should be chosen with lower values than the internal resistors to minimize errors caused by the +/-25% absolute value variation of the internal resistors. The internal resistors have high values in order to minimize these errors.

Low Battery Flag output (LBF)

This is an open drain output that switches low when the battery voltage falls below the detection threshold. An external pull-up resistor can be connected to this pin to allow it to interface to any voltage up to a maximum of 29V. Current in the pull-up resistor should be limited to a value below IBLOL.

DN67
ZXSC400 solution for 1W high powered LED

Mike Farley, Field Applications Engineer. December 2003

Description

The ZXSC400, although designed for small LEDs in LCD backlighting, is sufficiently flexible to provide an efficient 1W solution producing a nominal 350mA constant current source from 2 NiMH or NiCd cells.

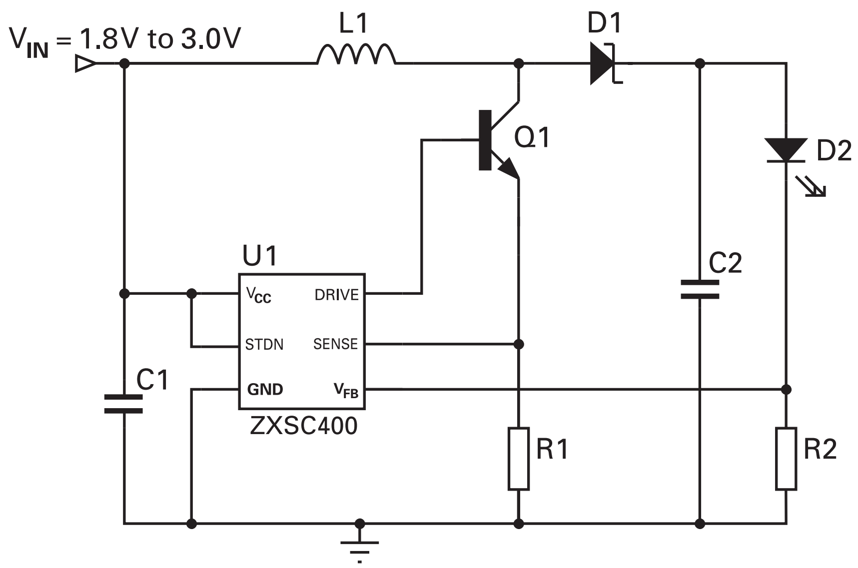


Figure 1 Schematic diagram

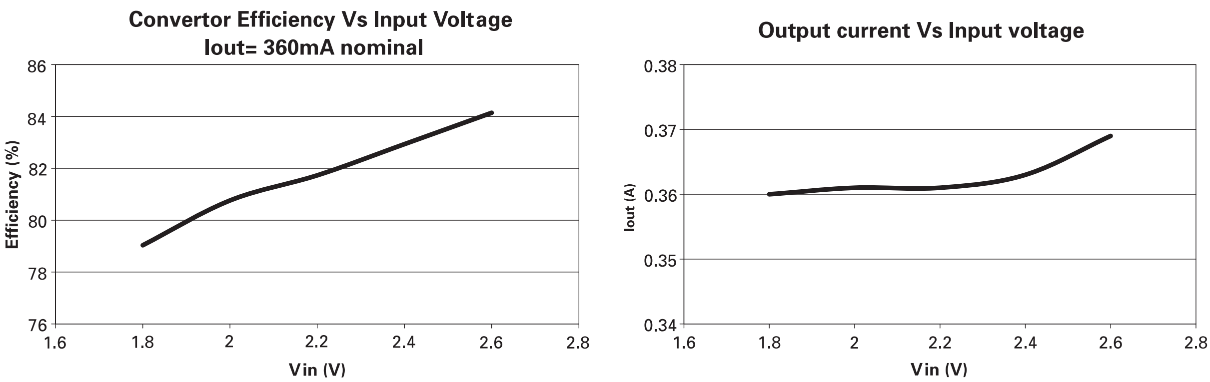


Figure 2 Performance graphs

Reference	Part number	Value	Manufacturer	Contact details
U1	ZXSC400E6		Zetex	www.zetex.com
Q1	FMMT617		Zetex	www.zetex.com
D1	ZHCS2000		Zetex	www.zetex.com
D2	LXHL-NW98		Lumileds	www.lumileds.com
L1	DO1608C-332	3.3μH	Coilcraft	www.coilcraft.com
C1	GRM42-6X5R226K6.3	22μF	Murata	www.murata.com
C2	GRM42-6X5R226K6.3	22μF	Murata	www.murata.com
R1(1)		17mΩ	Generic	NA
R2		0.82Ω	Generic	NA

Table 1 Bill of materials

NOTES:
(1) Actual in-circuit value, see notes overleaf

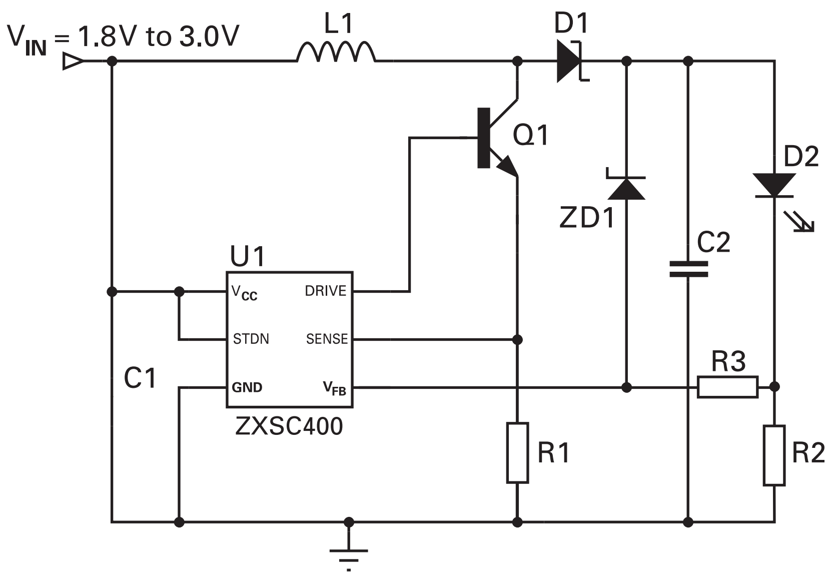


Figure 3 Open circuit protection

Additional BoM

AD1 - 5V6
R3 - 1KΩ

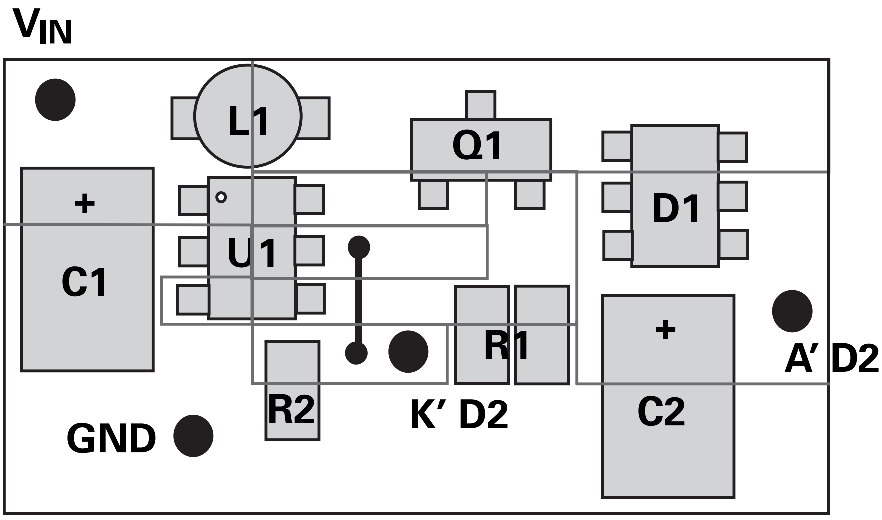


Figure 4 Layout suggestion

Note

For these approximate layout dimensions, R1 is 15mΩ. See note 3.

Notes:

1. D1 can be exchanged with a SOT23 ZHCS1000 with a loss of 5% efficiency.
2. Inductor DCR (DC resistance) strongly influences efficiency, keep below 0.1Ω.
3. R1 is small and it is strongly advised to take track resistance into account. A proven method is to source a 1A current from the Sense pin to the GND pin and check for 16-17mV. This resistor can be made from a 22mΩ in parallel with a 47mΩ (or a single 15mΩ resistor if available) with the PCB trace contributing the difference.
4. Open circuit protection can be added as shown below. The voltage rating of the small signal Zener diode ZD1 is not critical. It must be greater than the maximum forward voltage of the LED and less than the maximum V_{CE} rating of the switching transistor, 15V in the case of the FMMT617. The supply current in the open circuit condition is around 2mA.

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ZETEX SEMICONDUCTORS

DN68
ZXSC310 High power torch reference design

Description

This design note shows a typical ZXSC310 LED driver circuit for a high powered LED torch. The input voltage ranges from 0.7V to 1.6V with a maximum output current of 335mA at 1.4V input.

A typical schematic diagram is shown in Figure 1.

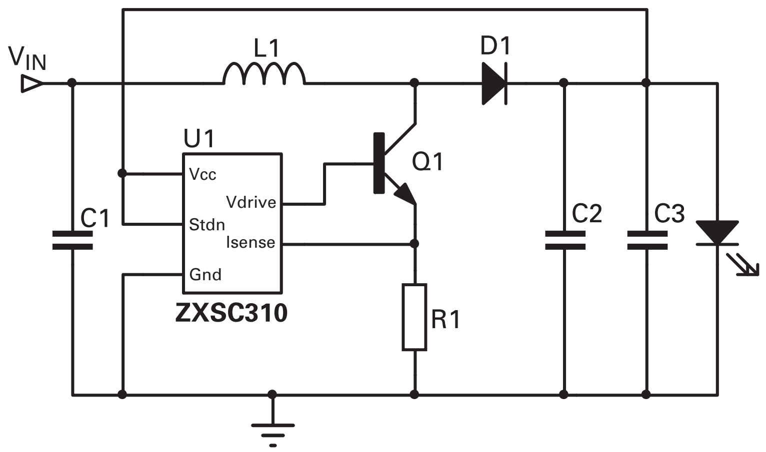

Figure 1 Schematic diagram

Reference	Value	Part number	Manufacturer	Contact details	Comments
U1		ZXSC310E5	Zetex	www.zetex.com	LED driver in SOT23-5
Q1		FMMT617	Zetex	www.zetex.com	Low sat. NPN in SOT23
D1	2A	ZHCS2000	Zetex	www.zetex.com	2A Schottky in SOT23
L1	7.5μH	DO3316P-153x2	Coilcraft	www.coilcraft.com	I_{SAT} = 3A
R1	19.5mΩ	Generic	Generic	NA	0805 size
C1	1μF	Generic	Generic	NA	
C2	220μF	Generic	Generic	NA	
C3	100μF	Generic	Generic	NA	

Table 1 Bill of materials

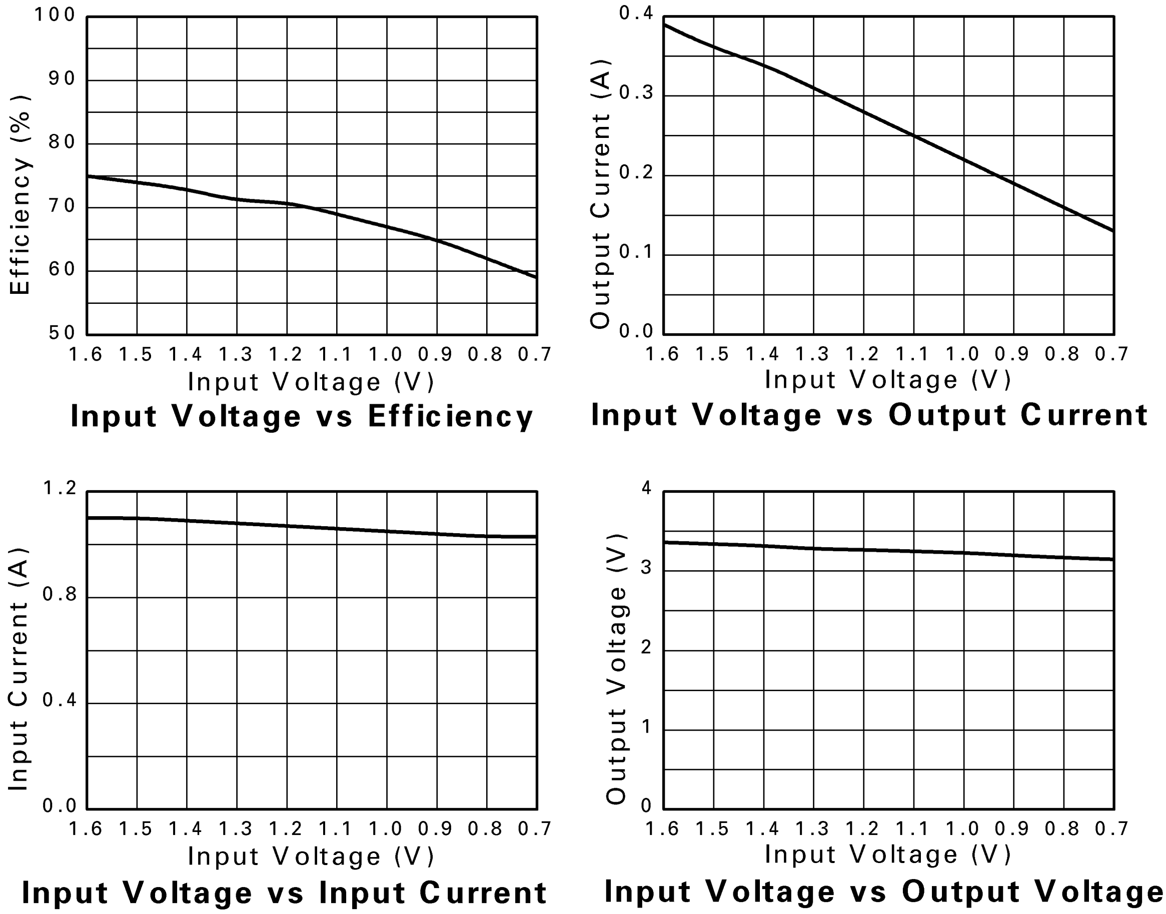

Figure 2 Performance graphs

DN69
ZXSC310 Garden light reference design

Description

This design note shows a typical ZXSC310 LED driver circuit for a solar power garden light. The input voltage ranges from1.7V to 2.5V with a maximum output current of 160mA at 2.4V input.

A typical schematic diagram is shown in Figure 1.

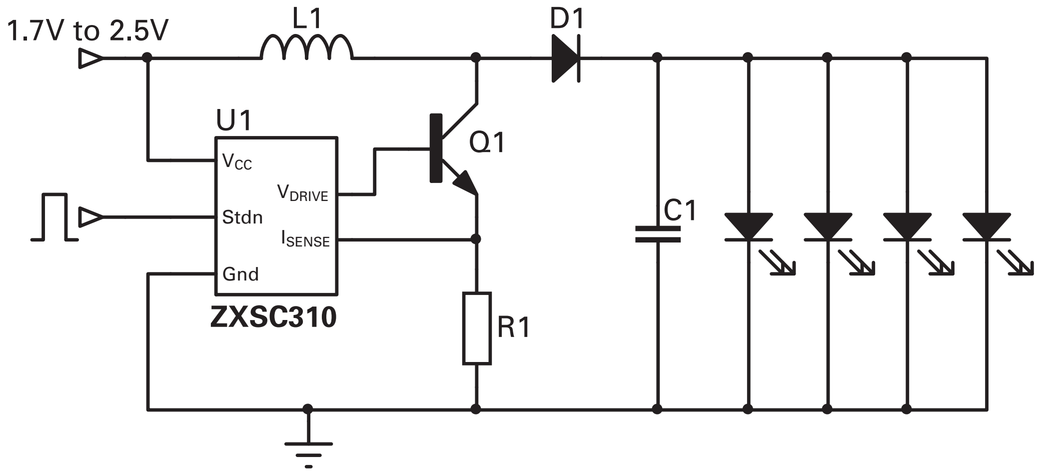

Figure 1 Schematic diagram

Ref	Value	Part number	Manufacturer	Contact details	Comments
U1		ZXSC310E5	Zetex	www.zetex.com	LED driver in SOT23-5
Q1		FMMT617	Zetex	www.zetex.com	Low sat NPN in SOT23
D1	500mA	ZHCS500	Zetex	www.zetex.com	0.5A Schottky in SOT23
L1	15µH	DO3316P-153	Coilcraft	www.coilcraft.com	I_{SAT} =3A
R1	70mΩ	Generic	Generic	NA	0805 size
C1	100µF	Generic	Generic	NA	

Table 1 Bill of materials

Total output current

Table 2 shows the maximum available output current and the current per LED for a given number of LEDs. An LED forward voltage of 3.5V is assumed.

Total LED Current (mA)	4 LEDs	5 LEDs	6 LEDs
176	44	35	29
163	41	33	27
153	38	31	25
141	35	28	23
131	33	26	22
119	30	24	20
110	27	22	18
97	24	19	16
89	22	18	15
80	20	16	13
70	18	14	12
61	15	12	10

Table 2 Total output current

Typical operating characteristics

(For typical application circuit where T_{amb} = 25°C unless otherwise stated)

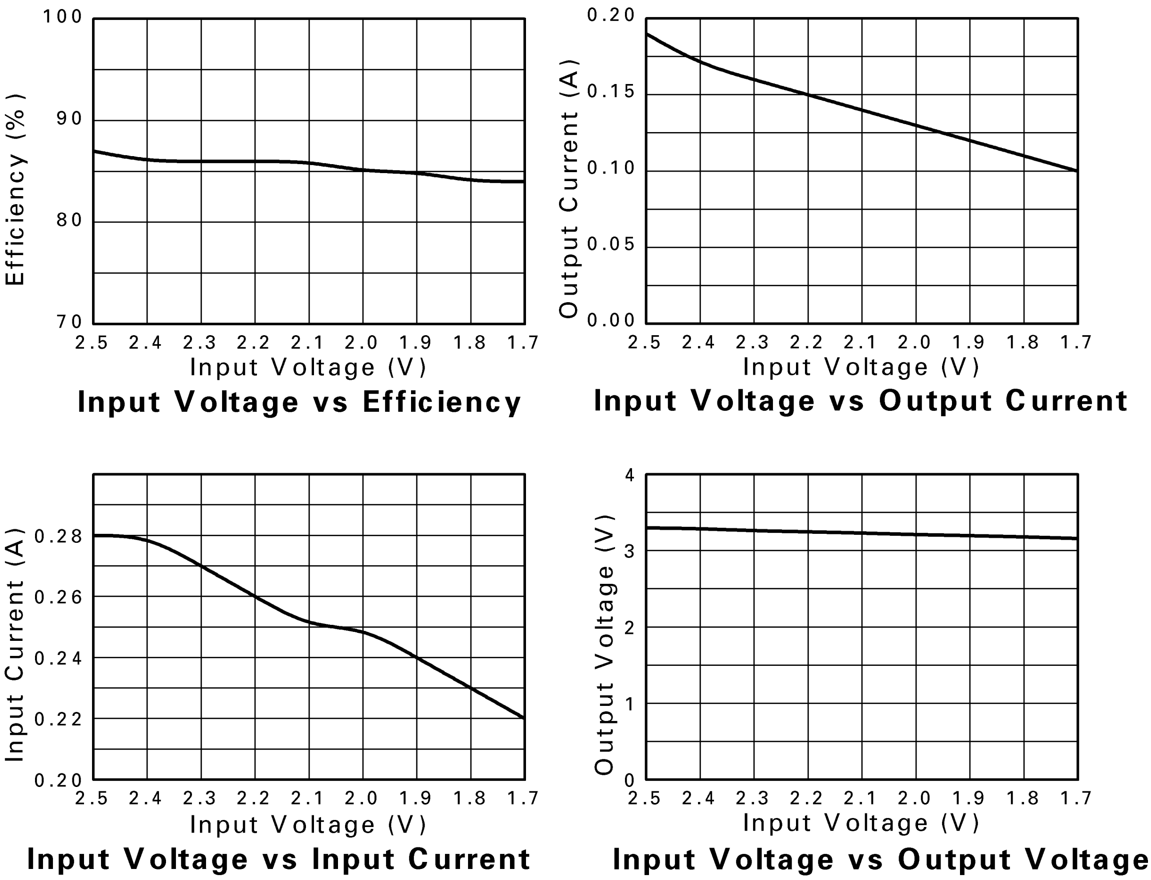

Figure 2 Performance graphs

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DN70

ZXSC400 Driving 2 serial high power LEDs

Description

This design note shows the ZXSC400 driving 2 serial LEDs. The input voltage ranges from 2V to 3.6V with a maximum output current of 360mA from 2.6V input.

Figure 1 shows a typical constant current solution with the ZXSC400 driving two 1W LEDs in series. The wide input voltage range allows the use of different battery cell combinations. This could be dual alkaline cells with voltage starting from 3V down to 2V or triple NiCad/NiMH cells with voltage starting from 3.6V down to 2.7V.

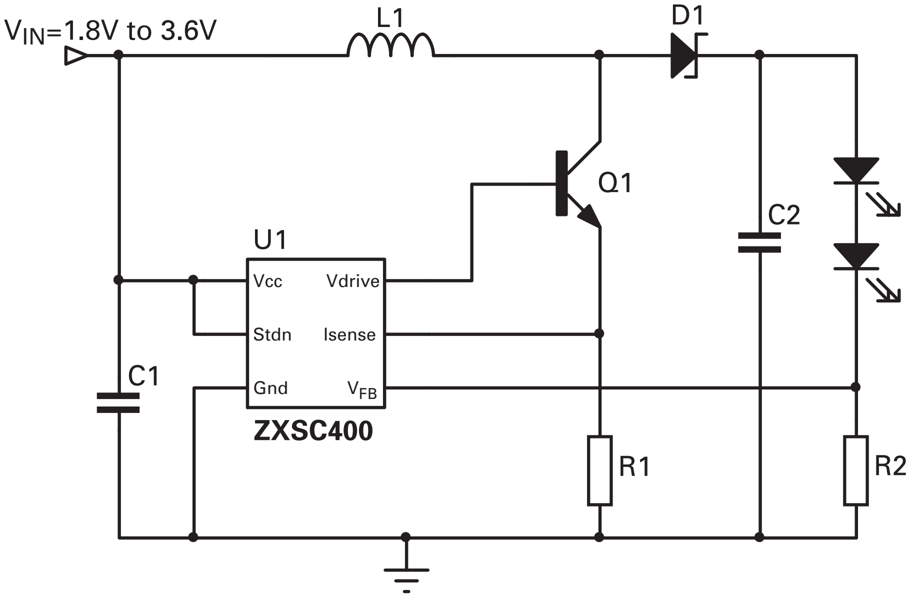


Figure 1 Schematic diagram

Ref.	Value	Part number	Manufacturer	Comments
U1		ZXSC400E6	Zetex	LED driver in SOT23-6
Q1		ZXTN25012EFH	Zetex	Low sat. NPN transistor in SOT23
D1	2A	ZHCS2000	Zetex	2A Schottky in SOT23
L1	22μH	Generic	Generic	I_{SAT} = 2A
R1	18mΩ	Generic	Generic	0805 size
R2	820mΩ	Generic	Generic	0805 size
R3	1KΩ	Generic	Generic	0805 size
C1	22uF/10V	Generic	Generic	
C2	100uF/10V	Generic	Generic	
C3	220nF/10V	Generic	Generic	0805 size

Table 1 Bill of materials

Typical operating characteristics

(For typical application circuit where T_{amb} = 25°C unless otherwise stated)

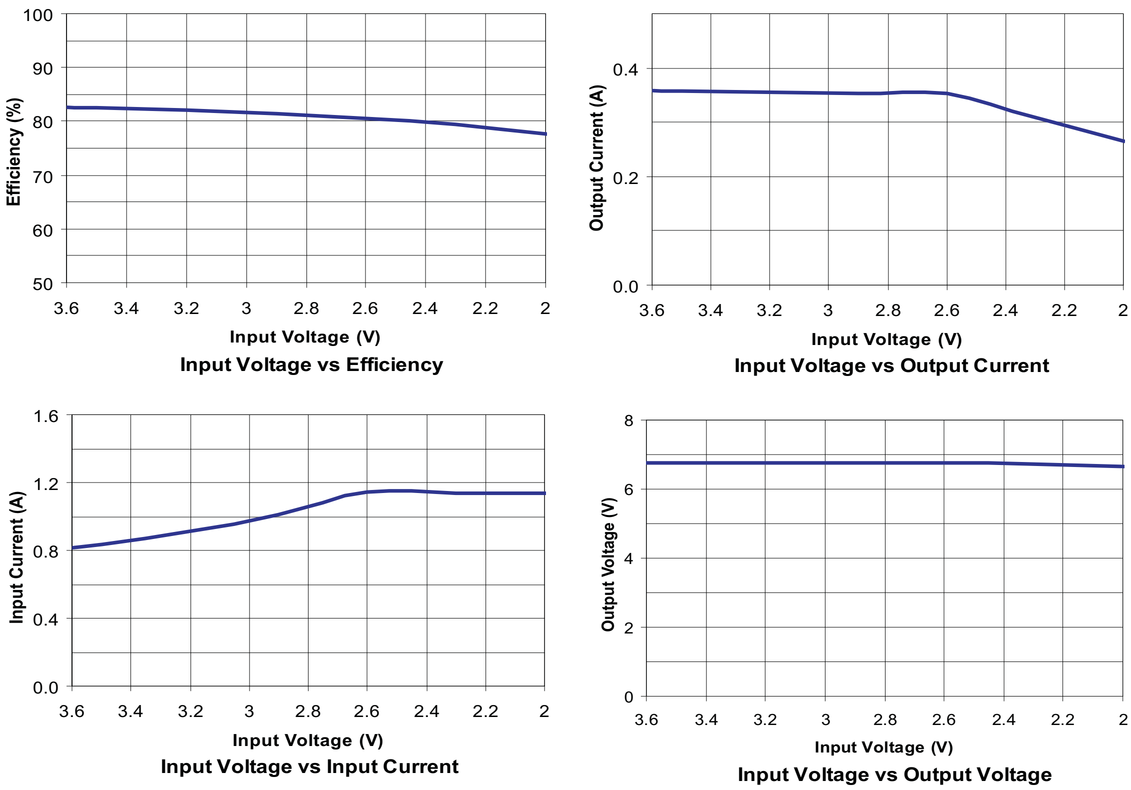


Figure 2 Performance graphs

ZETEX SEMICONDUCTORS

DN71
ZXSC400 Solution for Luxeon® V Star high powered LED

Description

This design note shows the ZXSC400 driving a Luxeon® V Star LED. The input voltage ranges from 4.2V to 5.4 V with a maximum output current of 700mA at 5V input.

A typical schematic diagram is shown in Figure 1.

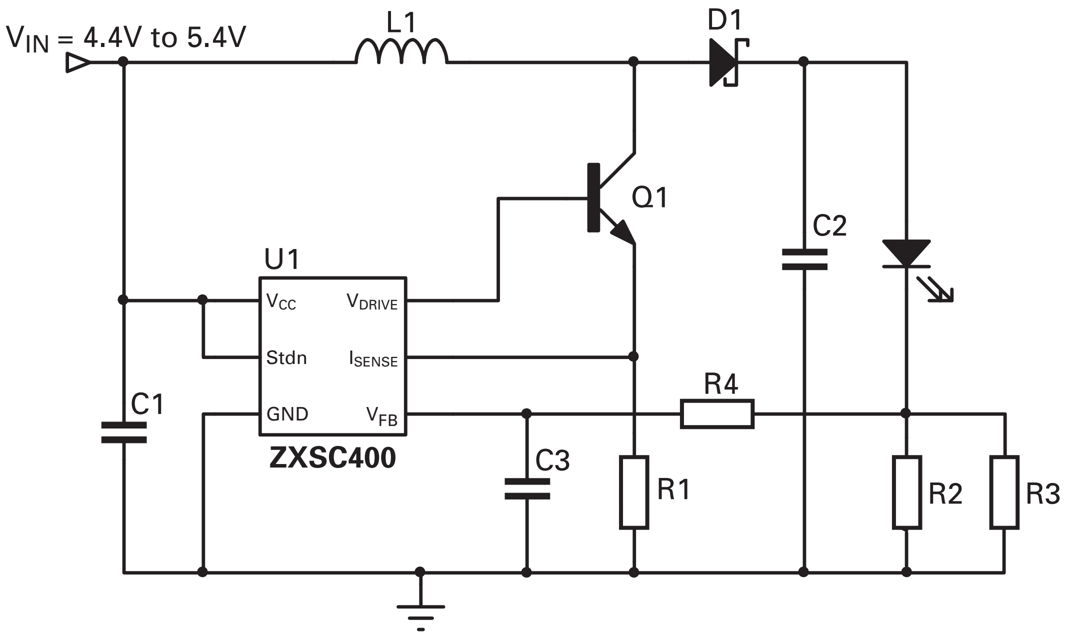


Figure 1 Schematic diagram

Ref.	Value	Part number	Manufacturer	Comments
U1		ZXSC400E6	Zetex	LED driver in SOT23-6
Q1		ZXTN25012EFH	Zetex	Low sat. NPN in SOT23
D1	2A	ZHCS2000	Zetex	2A Schottky in SOT23
L1	22μH	Generic	Generic	I_{SAT} = 2A
R1	18mΩ	Generic	Generic	0805 size
R2, R3	820mΩ	Generic	Generic	0805 size
R4	1kΩ	Generic	Generic	0805 size
C1	22μF/10V	Generic	Generic	
C2	100μF/10V	Generic	Generic	
C3	100nF/10V	Generic	Generic	0805 size

Table 1 Bill of materials

Typical operating characteristics

(For typical application circuit where T_{amb} = 25°C unless otherwise stated)

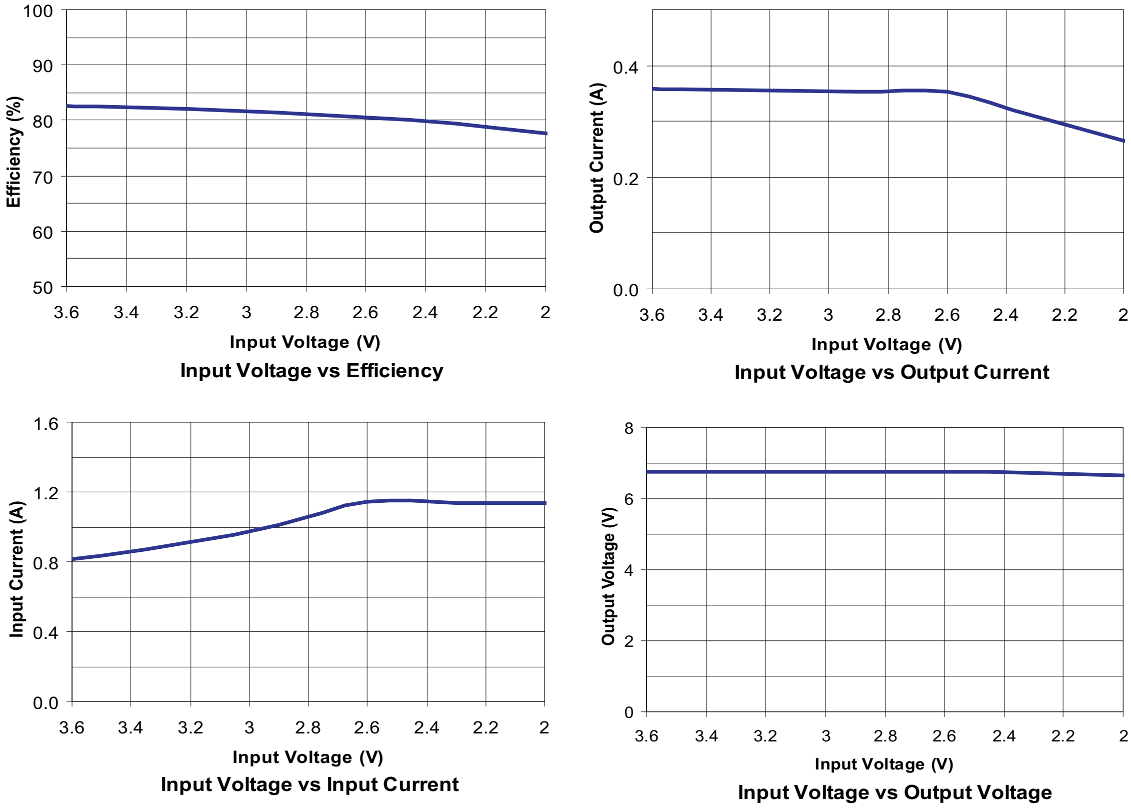


Figure 2 Performance graphs

ZETEX
SEMICONDUCTORS

DN72
ZXLD1101 Driving 8 series LEDs

Description

This design note shows the ZXLD1101 driving 8 series connected LEDs. The input voltage ranges from 4.2V to 5.2V with a maximum output current of 24mA at 5V input.

A typical schematic diagram is shown in Figure 1.

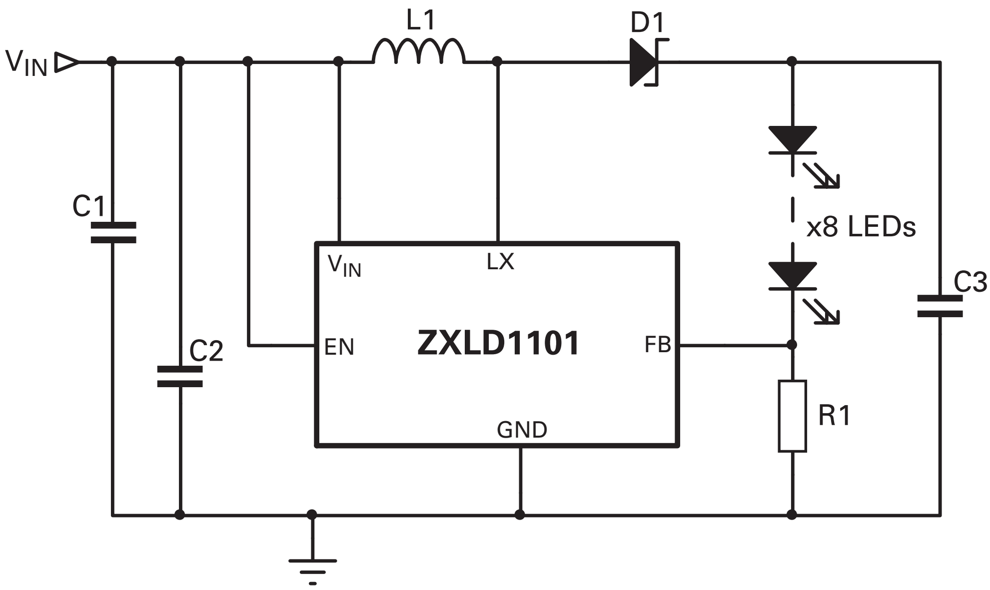


Figure 1 Schematic diagram

Ref.	**Value**	**Part number**	**Manufacturer**	**Comments**
U1		ZXLD1101E6	Zetex	LED Driver in SOT23-6
D1	1A	ZHCS1000	Zetex	1A Schottky in SOT23
L1	33μH	Generic	Generic	
R1[(1)]	0Ω	Generic	Generic	0805 size
C1	100μF	Generic	Generic	
C2	1μF	Generic	Generic	
C3	10μF	Generic	Generic	

Table 1 Bill of materials

NOTES:

(1) R1 is set to zero. It shows the maximum output power characteristic of the LED driver. A regulated LED current below the maximum value can be set by: $I_{LED} = V_{FB}/R1$, where $V_{FB} = 0.1V$.

Typical operating characteristics

(For typical application circuit where T_{amb} = 25°C unless otherwise stated)

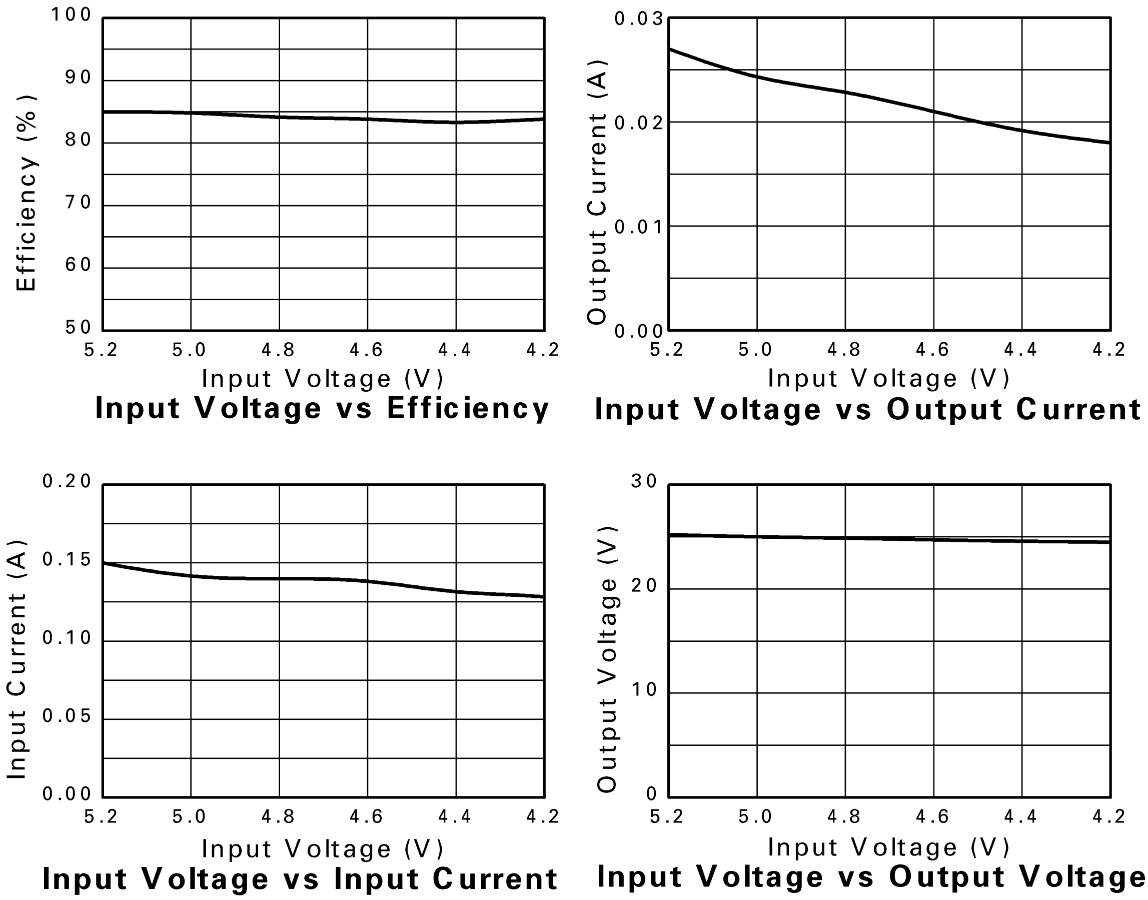


Figure 2 Performance graphs

DN73
ZXSC300 Step down converter for 3W LED

Description

This design note shows the ZXSC300 or ZXSC310 driving a 3W LED. The input voltage ranges from 6.2V to 3.8V with a maximum output current of 1.11A at 6V input.

A typical schematic diagram is shown in Figure 1.

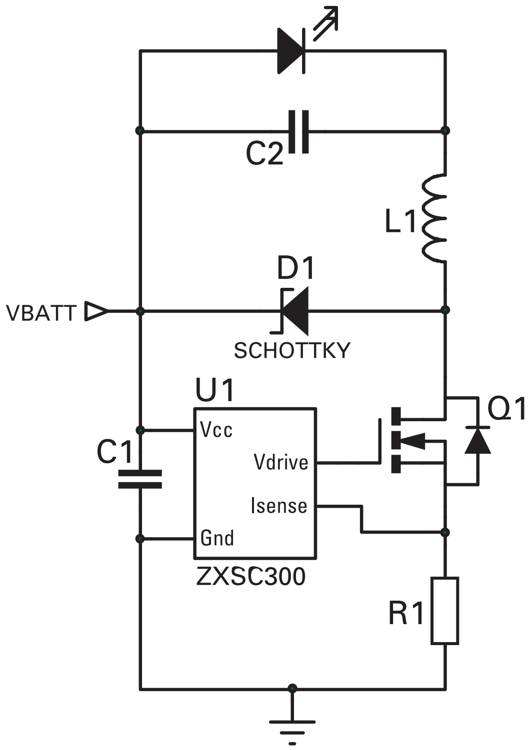


Figure 1 Schematic diagram

Ref.	Value	Part number	Manufacturer	Comments
U1		ZXSC300/310	Zetex	LED Driver in SOT23-5
Q1		ZXMN2A01F	Zetex	SOT23 MOSFET
D1	1A	ZHCS1000	Zetex	1A Schottky in SOT23
L1	22μH	Generic	Generic	I_{SAT} = 3A
R1	20mΩ	Generic	Generic	0805 size
C1	100μF	Generic	Generic	
C2	100μF	Generic	Generic	

Table 1 Bill of materials

Typical operating characteristics

(For typical application circuit where T_{amb} = 25°C unless otherwise stated)

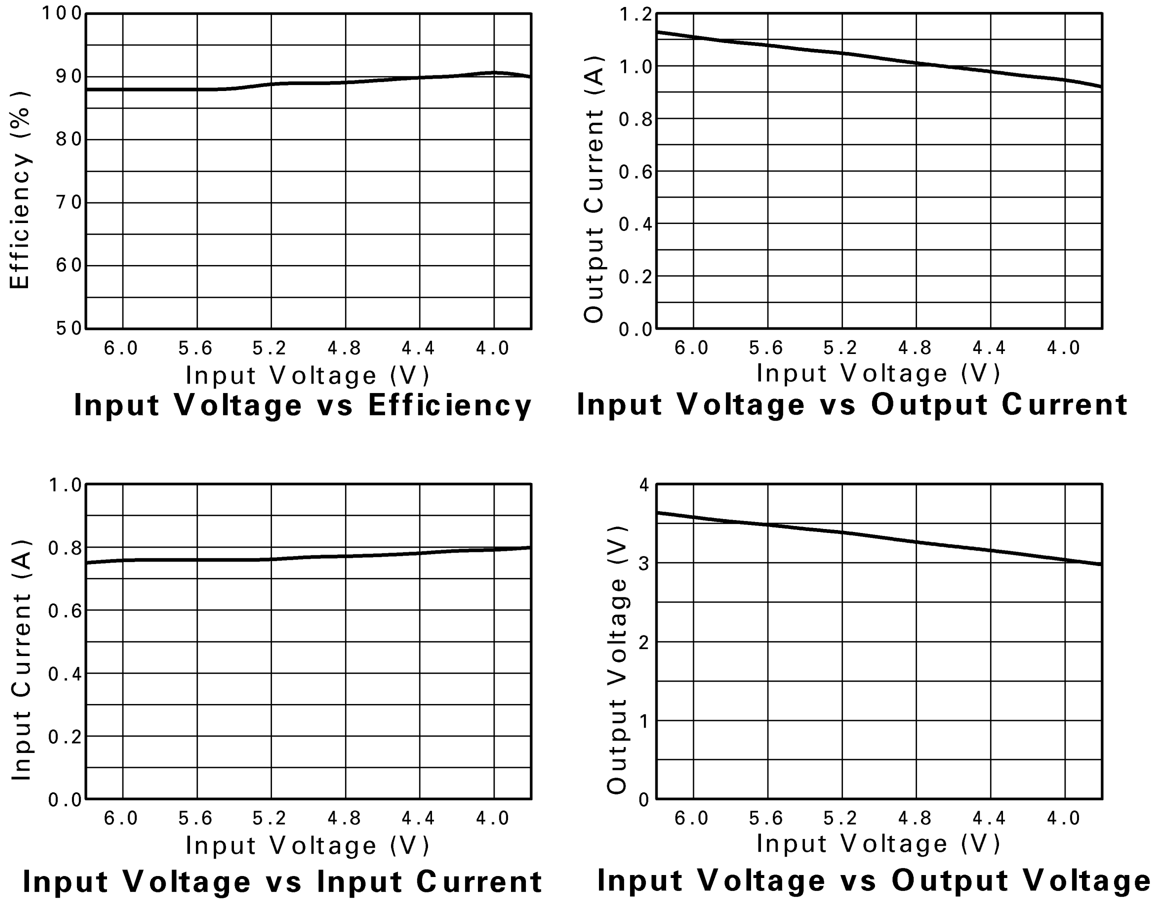


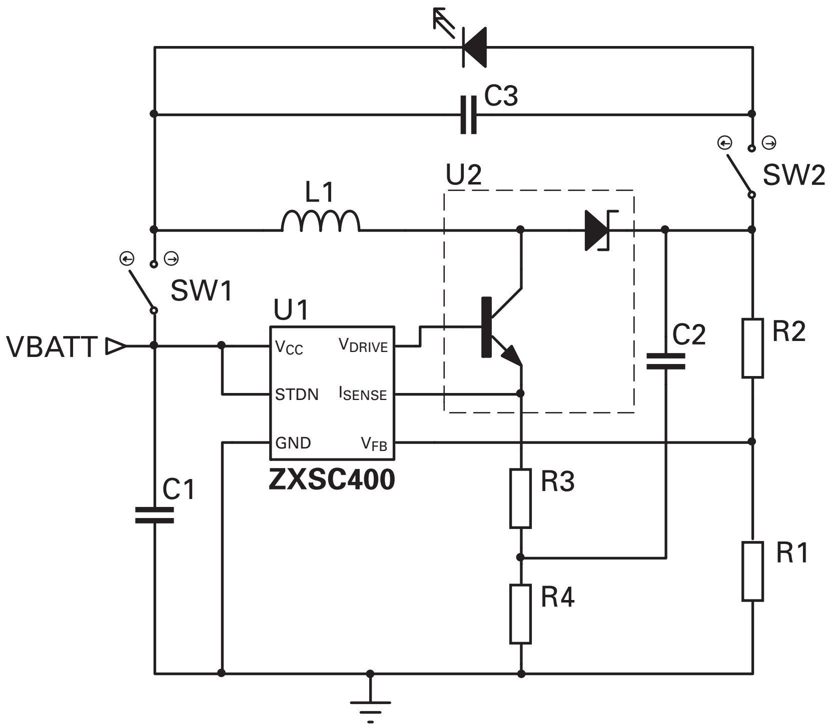
Figure 2 Performance graphs

DN74
ZXSC400 Photoflash LED reference design

Description

This design note shows the ZXSC400 driving a Photoflash LED. The input voltage is 3V with a maximum pulsed output current of 1A for 2ms.

A typical schematic diagram is shown in Figure 1.



Charging mode: SW1 closed, SW2 open
Discharging mode: SW1 open, SW2 closed

Figure 1 Schematic diagram

Operation

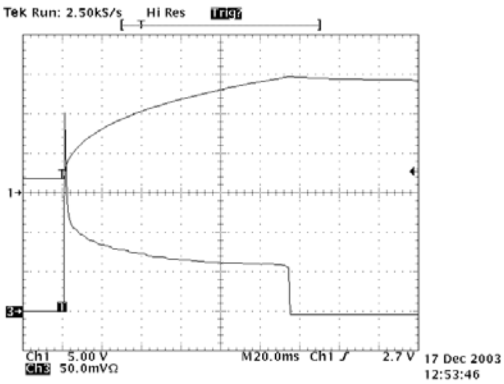
In charging mode, SW1 is closed and SW2 is open the ZXSC400 is configured as a typical boost converter, charging capacitor C2 up the regulated output voltage set by the ratio of R1 and R2. This is typically 16V. The peak current of the converter (current drawn from the battery) is controlled by R3 plus R4, and is typically 280mA for this application. When C2 is charged to 16V the SW1 is opened and SW2 is closed, converting the ZXSC400 to a step down converter to provide a 1A constant current for 2ms to the photoflash LED. During step down operation, current flows from C2, through the photoflash LED, L1, U2 and is returned to C2 through R3. This means that the peak current is set at a higher value than in charging mode, typically 1A. When the current reaches it's peak value, U2 is switched off and current flows from L1 through the Schottky diode in U2, to the photoflash LED. This cyclic process is repeated until C2 is discharged.

Ref	Value	Part number	Manufacturer	Comments
U1		ZXSC400E6	Zetex	LED Driver in SOT23-6
U2		ZX3CDBS1M832	Zetex	Dual NPN and Schottky
L1	12µH	Generic	Generic	I_{SAT}=1A
R1	10kΩ	Generic	Generic	0805 size
R2	510kΩ	Generic	Generic	0805 size
R3	22mΩ	Generic	Generic	0805 size
R4	100mΩ	Generic	Generic	0805 size
C1	1µF	Generic	Generic	
C2	150µF	Generic	Generic	
C3	1µF	Generic	Generic	

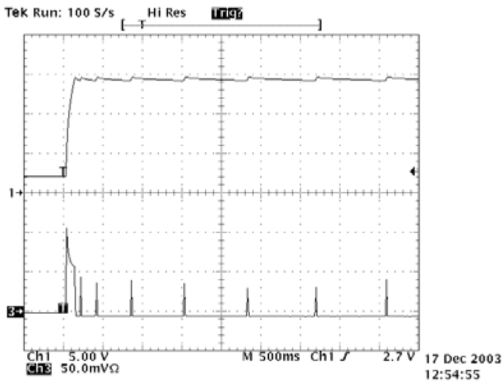
Table 1 Bill of materials

Typical operating waveforms

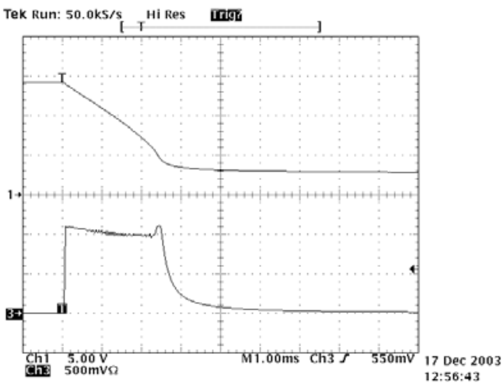
(For typical application circuit where V_{BATT} = 3V and T_{amb} = 25°C unless otherwise stated)



Charging mode
Top trace: C2 charging
Bottom trace: input current



Refreshing C2
Top trace: C2 charging
Bottom trace: input current



Discharging mode (flash)
Top trace: C2 charging
Bottom trace: input current

Figure 2 Performance graphs

ZETEX SEMICONDUCTORS

DN75
ZXSC310 Solar powered garden light reference design

Description

This design note shows a typical ZXSC310 LED driver circuit for a solar powered garden light. The input voltage ranges from 0.4V to 1.6V with a maximum output current of 43mA at 1V input.

A typical schematic diagram is shown in Figure 1.

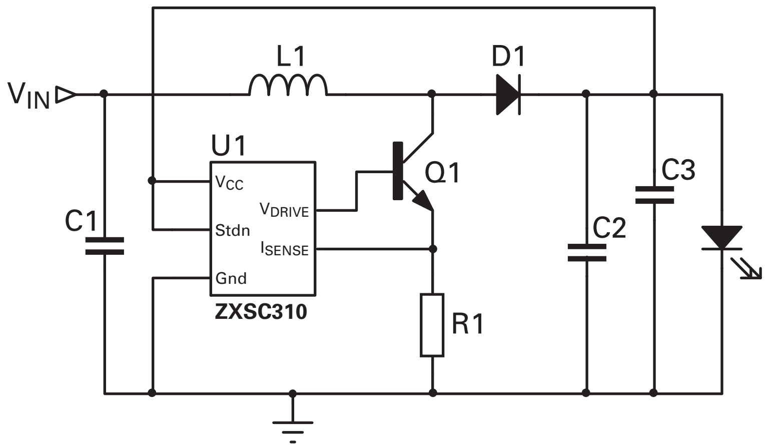


Figure 1 Schematic diagram

Ref.	**Value**	**Part Number**	**Manufacturer**	**Comments**
U1		ZXSC310E5	Zetex	LED Driver in SOT23-5
Q1		FMMT617	Zetex	Low sat NPN in SOT23
D1	1A	ZHCS1000	Zetex	1A Schottky in SOT23
L1	37μH			
R1	100mΩ	Generic	Generic	0805 size
C1	1μF	Generic	Generic	
C2	22μF	Generic	Generic	
C3	10μF	Generic	Generic	

Table 1 Bill of materials

DN75

Typical operating characteristics

(For typical application circuit where T_{amb} = 25°C unless otherwise stated)

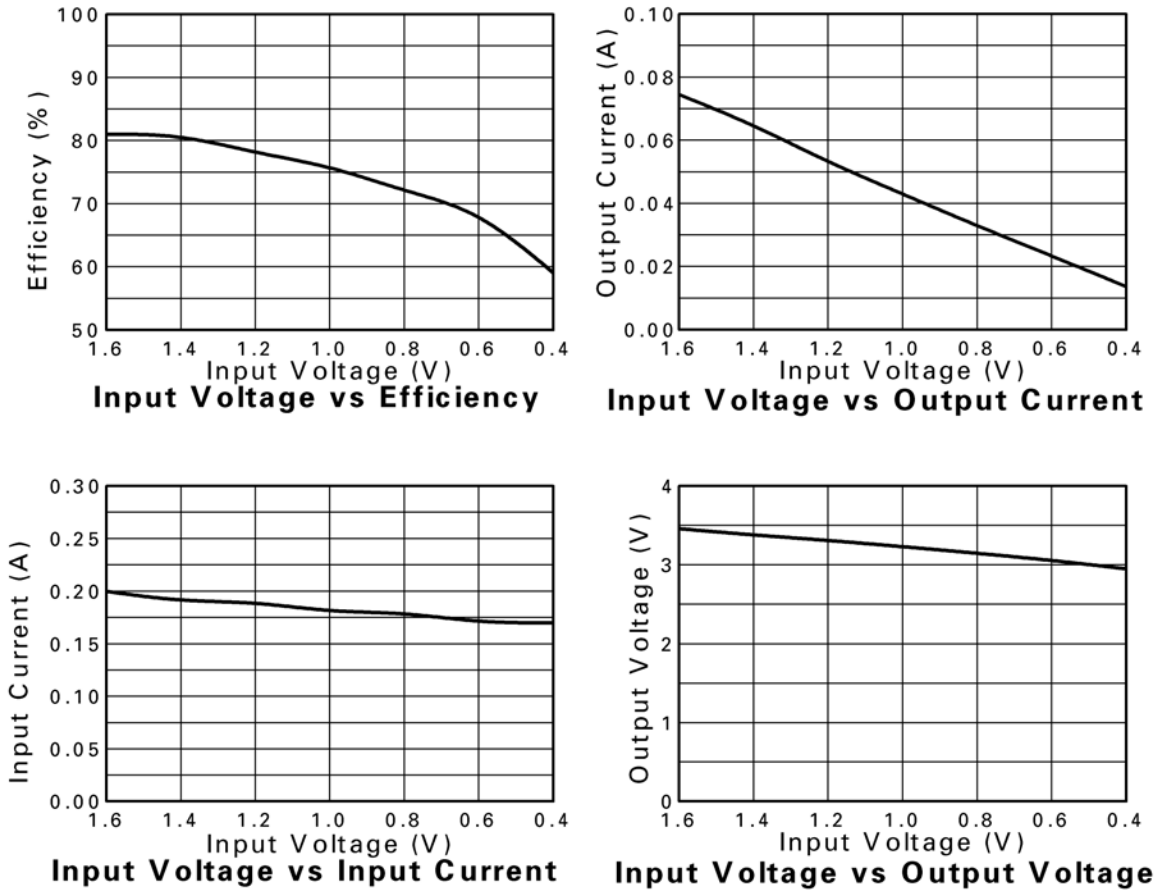


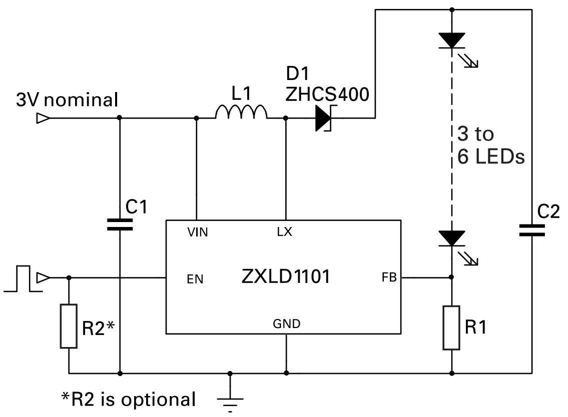
Figure 2 Performance graphs

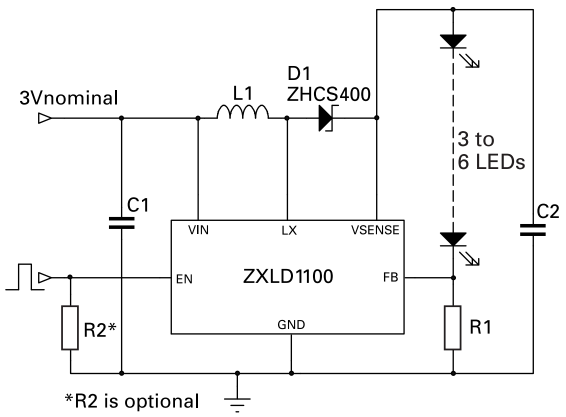
DN76
ZXLD1100 and ZXLD1101 driving from 3 to 6 LEDs

Description

This design note shows the ZXLD1100 and ZXLD1101 driving series connected LEDs. The input voltage range is 2.5V to 5.5V. The same circuit can be used for up to 6 LEDs.

The ZXLD1100 contains onchip open circuit LED protection. This function would require an additional Zener and resistor with the ZXLD1101.





Note: LED current is set to 15mA

Figure 1 Schematic diagrams

Ref.	Value	Package	Part number	Manufacturer	Contact details	Notes
U1		TSOT23-5	ZXLD1101ET5	Zetex	www.zetex.com	LED driver IC
U1		SC706	ZXLD1100H6	Zetex	www.zetex.com	LED driver IC
D1	400mA	SOD323	ZHCS400	Zetex	www.zetex.com	400mA Schottky diode
L1	10µH		CMD4D11-100MC	Sumida	www.sumida.com	1mm height profile
R1	6.8Ω	0603	Generic	Generic		
R21	100kΩ	0603	Generic	Generic		
C1	1µF	0603	Generic	Generic		
C2	1µF	0603	Generic	Generic		
LEDs			NSCW215	Nichia	www.nichia.com	6pcs per board

Table 1 Bill of materials

Typical operating characteristics

(For typical application circuit where T_{amb} = 25°C unless otherwise stated)

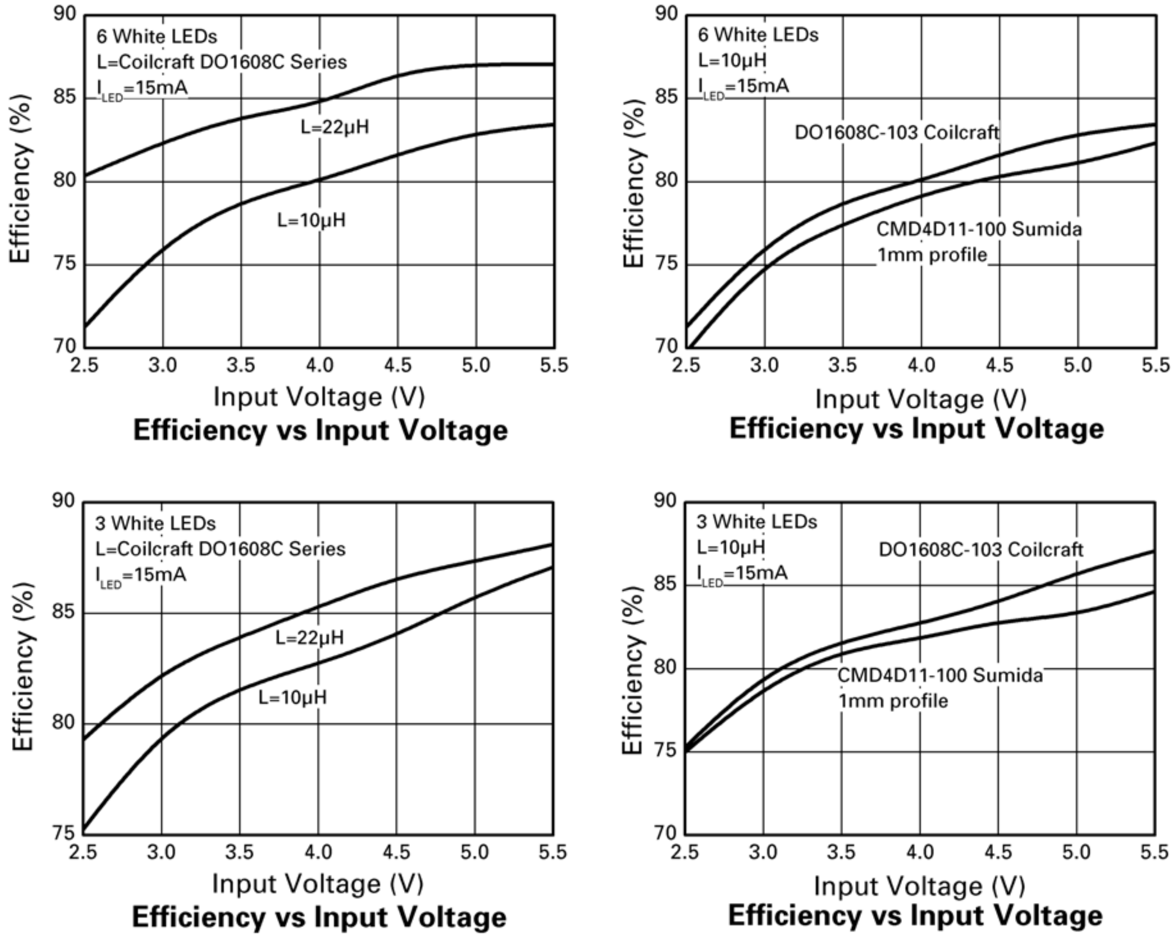


Figure 2 Performance graphs

DN78
ZXSC310 with reverse polarity protection

Ray Liu - Applications Engineer, Zetex Semiconductors

Description

The schematic diagram shown in Figure 1 is a typical example of the ZXSC310 used in a LED flashlight application. The input voltage can either be one or two alkaline cells. If the battery is put in the flashlight the wrong way, the reverse polarity can damage the ZXSC310 and switching transistor, Q1. Implementing a mechanical reverse protection method can be expensive, and not always reliable. This paper describes methods of electronic reverse protection, without efficiency loss, for the ZXSC series ICs and related LED flashlight application circuits.

Circuit problems caused by the reverse polarity battery

If a negative voltage appears at the input terminal of Figure 1 then reverse current will flow from the ground pin of the ZXSC310 to the V_{CC} terminal and back to the battery. This current is high and will damage the ZXSC310. Some of this reverse current will also flow through the V_{DRIVE} terminal of the ZXSC310 and into Q1 base-collector completing the circuit to the battery.

The reverse current through base-collector of Q1 turns the transistor on in the reverse direction and causes high current to flow from ground, through emitter-collector to the battery, resulting in battery drainage and possible damage to the switching transistor, Q1.

A common method of reverse polarity protection

A common method of reverse protection is to add a Schottky diode in series with the battery positive. The problem with this method of reverse protection is that there is a loss of efficiency due to the forward voltage drop of the diode, typically 5% to 10% depending upon input voltage, reducing the usable battery life. The proposed method of reverse protection for the ZXSC series IC's gives full protection with **no** loss of efficiency.

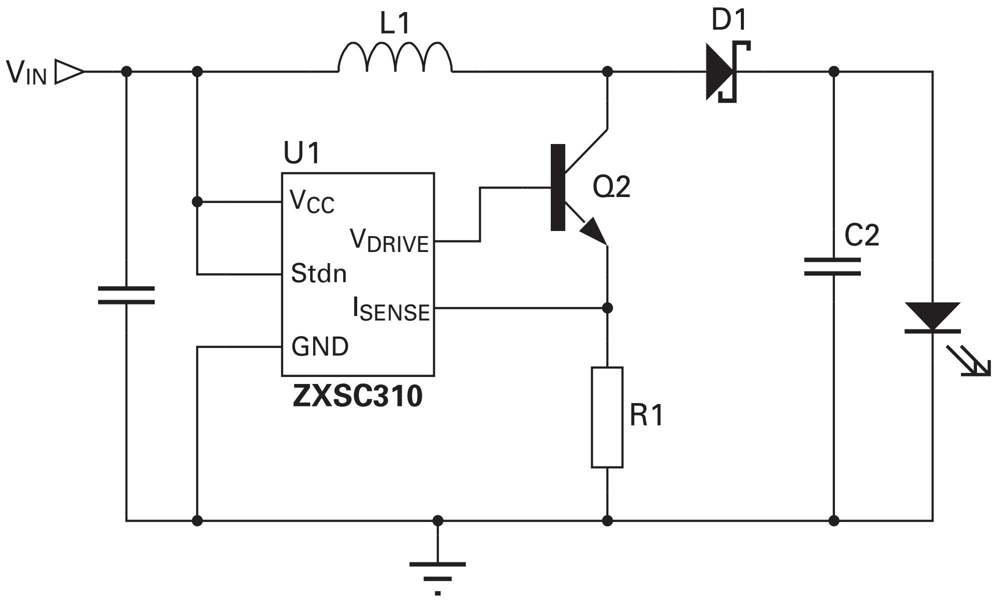


Figure 1 Schematic diagram

Reverse protection without efficiency loss

By adding current limiting resistor and Schottky diode, the reverse current flow can be eliminated without a loss of efficiency.

Flashlight circuit with bootstrap

For the bootstrap circuit in Figure 2, the current through the ZXSC310 is blocked by the reversed biased Schottky diode, D1.

The current from V_{DRIVE}, which turns on Q1 in the reverse direction, is diverted via D2 back to the battery so that Q1 does not turn on. R2 is a current limiting resistor to control this V_{DRIVE} current. This value is typically set to 100Ω to 500Ω to minimize battery current drain without affecting the normal operation of the circuit.

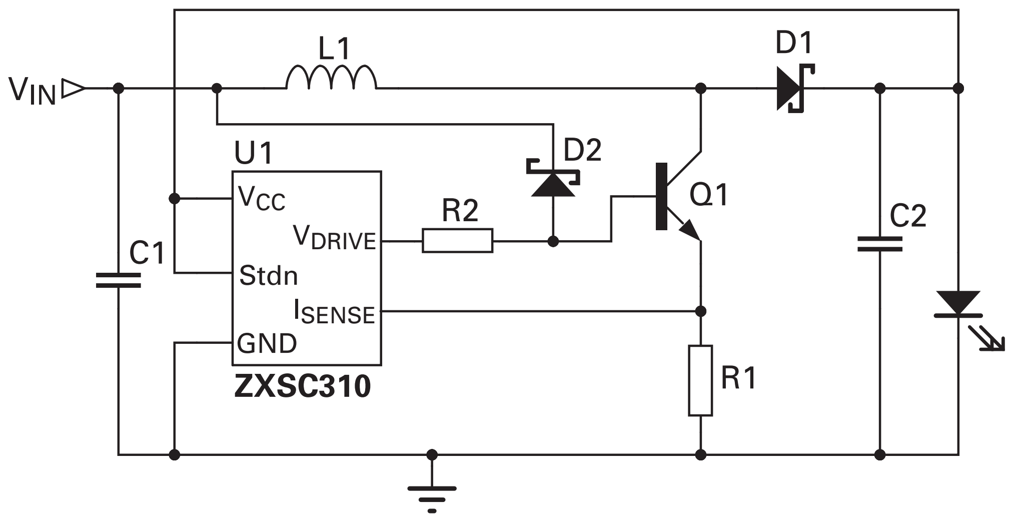


Figure 2

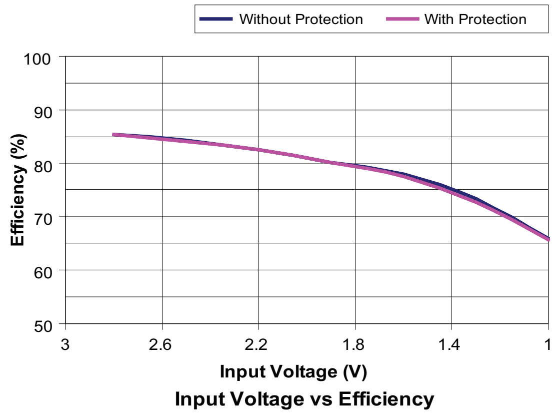
Ref	Value	Part number	Manufacturer	Comments
U1		ZXSC310E5	Zetex	LED driver in SOT23-5
Q1		ZXTN25012EFL	Zetex	Low sat. NPN in SOT23
D1	750mA	BAT750	Zetex	750mA Schottky in SOT23
D2(1)	200mA	BAT54	Zetex	200mA Schottky in SOT23
L1	68μH	Generic	Generic	I_{SAT}>0.4A, R<0.8Ω
R1	270mΩ	Generic	Generic	0805 size
R2(1)	100Ω	Generic	Generic	0805 size
C1	10μF/6.3V	Generic	Generic	
C2	22μF/6.3V	Generic	Generic	

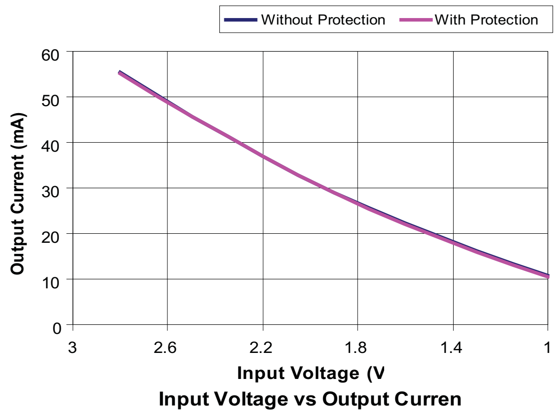
Table 1 Bill of materials

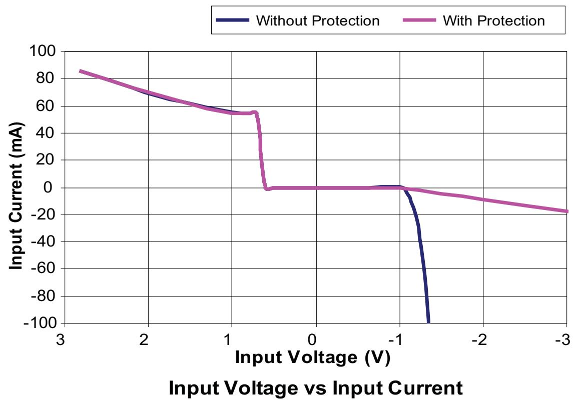
NOTES:
(1) Add for reverse protection

Typical operating characteristics

(For typical application circuit where T_{amb} = 25°C unless otherwise stated)







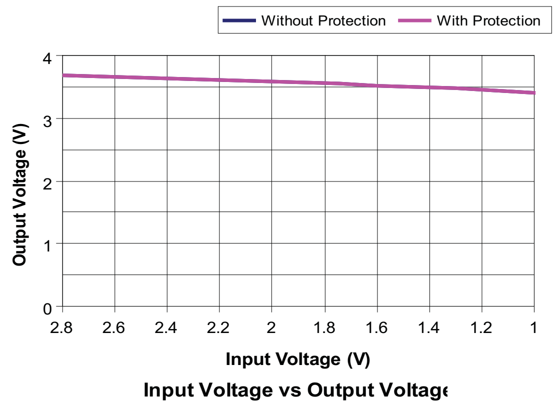


Figure 3 Performance graphs

Other circuit examples using reverse polarity protection

Flashlight circuit without bootstrap

The circuit shown in Figure 4 is for an LED flashlight application without bootstrap. As described previously, reverse current can flow from the GND terminal to V_{CC} and back to the battery. To block this current path an extra diode, D2b, is added. It is recommended that a Schottky diode be used for this application to maximize the start-up input voltage from $V_{CC(MAX)}$ to $V_{CC(MIN)}$ + D2b V_F, 3V to 1V. The Schottky diode, D2a, and resistor, R2, work in the same way as described in the bootstrap circuit in Figure 2. A dual Schottky diode, BAT54S, is recommended for D2 in order to achieve low component count.

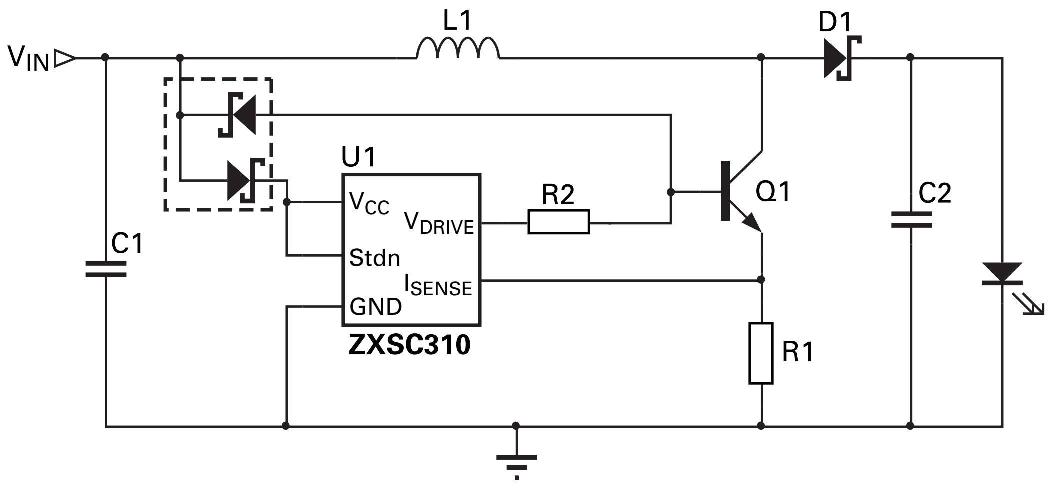


Figure 4 LED flashlight application without bootstrap

Other circuit examples using reverse polarity protection

Flashlight circuit without bootstrap

Figure 5 is a step down converter with reverse polarity protection. The main application for this circuit is a four alkaline cell flashlight driving a high powered LED. Again the protection circuit operates as described above. A dual Schottky diode, BAT54S, is recommended for D2 in order to achieve low component count.

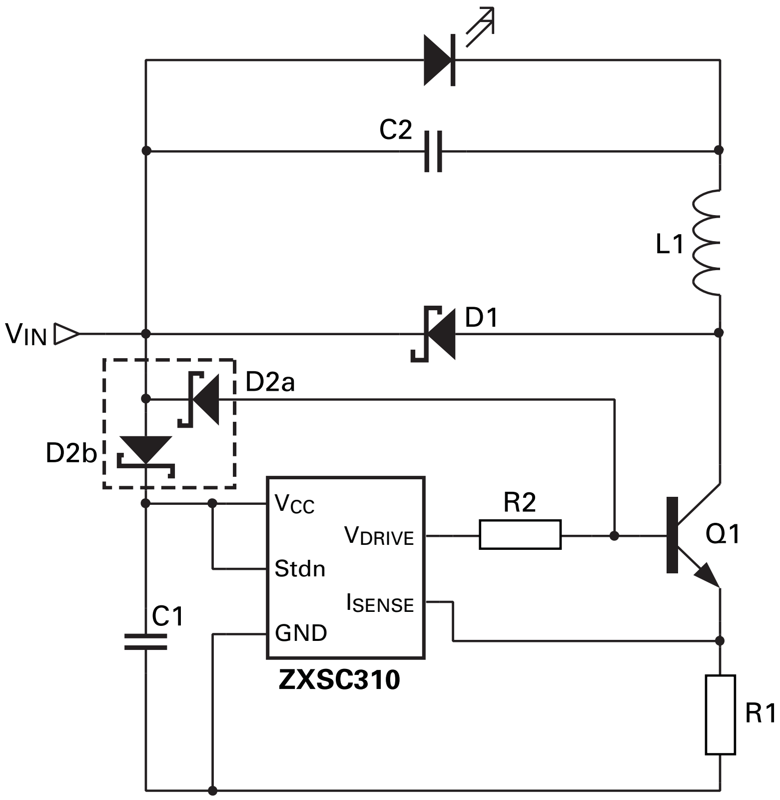


Figure 5 Step down converter with reverse polarity protection

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ZETEX SEMICONDUCTORS

DN79
ZXSC400 1W LED driver

Neil Wolstenholme, Applications Engineer, Zetex Semiconductors plc

Description

ZXSC400 is configured to the reference design below. The target application is a 1W white LED driven from a two cell NiCd/NiMH or alkaline battery input for flashlights and high powered LED driving.

The supply voltage for ZXSC400 reference design is: V_{IN} = 1.8V ~ 3V.

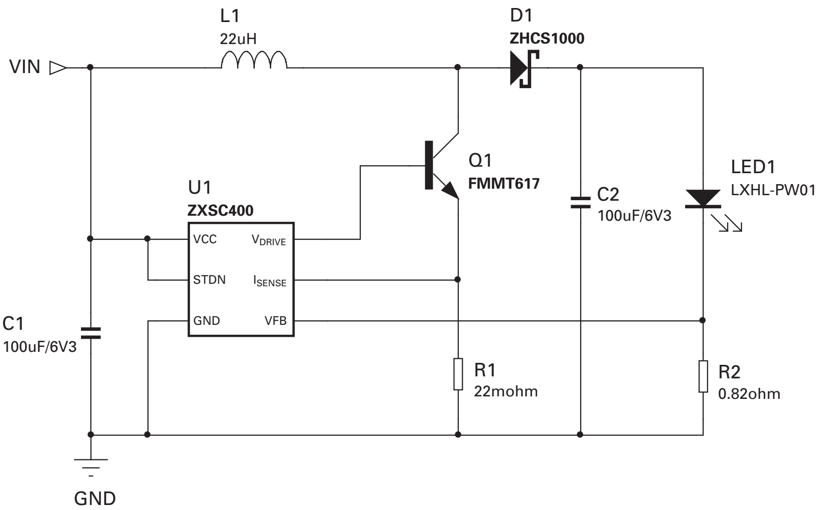


Figure 1 Schematic diagram

Ref.	Value	Package	Part number	Manufacturer	Contact details	Notes
U1	N/A	SOT23-6	ZXSC400E6	Zetex	www.zetex.com	Boost converter
Q1	N/A	SOT23	FMMT617	Zetex	www.zetex.com	Low sat NPN transistor
D1	40V/1A	SOT23	ZHCS1000	Zetex	www.zetex.com	40V/1A Schottky diode
L1	22uH/2.5A	N/A	DO3316P-223	Coilcraft	www.coilcraft.com	22μH/2.5A SMT inductor
R1	22mΩ	0805		Generic	NA	0805 5% tolerance
R2	0.82Ω	0805		Generic	NA	0805 5% tolerance
C1	100μF/6V3	1812	18126D107KAT2A	AVX	www.avx.com	100μF/6V3/X5R/1812
C2	100μF/6V3	1812	18126D107KAT2A	AVX	www.avx.com	100μF/6V3/X5R/1812
LED1	1W	N/A	LXHL-PW01	Lumileds	www.lumileds.com	1W white LED emitter

Table 1 Bill of materials

Performance

Increasing efficiency

On ZXSC400 reference design, R1 is set to 22mΩ to ensure that the LED current is regulated over the full input voltage range of 3V ~ 1.8V. For improved efficiency R1 can be changed to a 33mΩ resistor but LED current will not be regulated below 2V. See Figure 2, Performance graphs.

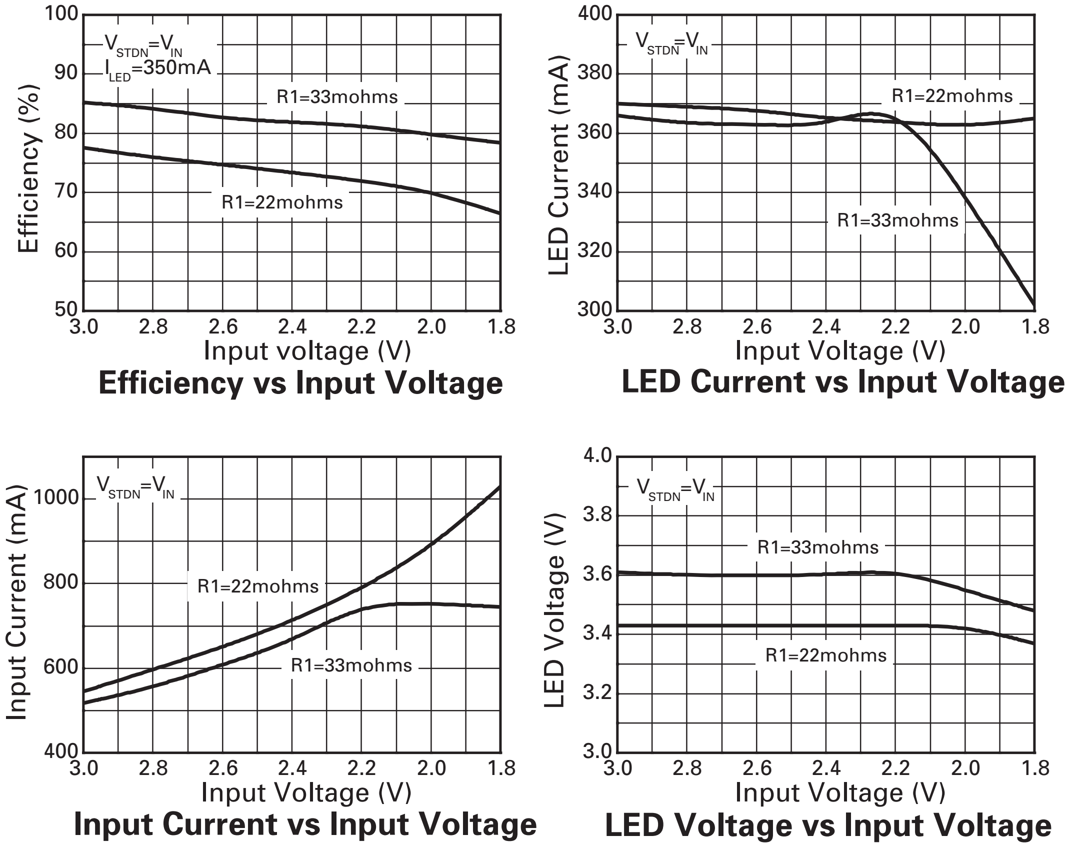


Figure 2 Performance graphs

DN83
LED MR16 Lamp solution using the ZXLD1350 LED driver

Neil Chadderton, Colin Davies, Roger Heap, Zetex Semiconductors

Introduction

Lighting class LEDs are now available that deliver the brightness, efficacy, lifetime, color temperature, and white point stability required for general illumination. As a result, these LEDs are being adopted into most general lighting applications including roadway, parking area and indoor directional lighting. LED-based luminaires reduce Total-Cost-of-Ownership (TCO) in these applications through maintenance avoidance and reduced energy costs.

MR16 lamps are one variety of Multifaceted Reflector (MR) lamps that have traditionally employed a halogen filament capsule as the light source. They are used in many retail and consumer lighting applications where their size, configurability, spot-lighting capability and aesthetics provide utility and creativity. Their low efficiency, heat generation (an issue for illuminating heat sensitive subjects and materials) and halogen capsule handling issues are typically cited among the disadvantages of the technology. They typically operate from 12V AC or 12V DC, though designs for 6V to 24V are also popular and as such require a step-down transformer to allow use from offline supplies. This is usually effected with conventional electromagnetic or electronic transformers.

With the advancement of HB (High Brightness) LED technologies, MR16 lamps can now be realized with an alternate light source. This hybrid solution can yield a cost effective, long-life, maintenance free, cooler operating unit which has not been previously possible.

Image courtesy of Lighting Research Center

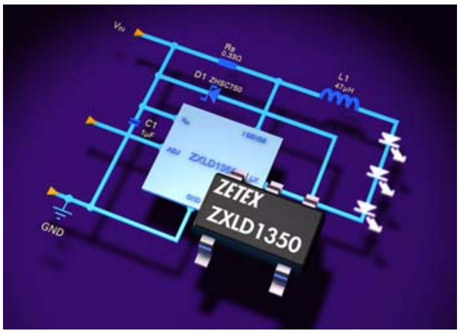
Figure 1 MR16 Lamps (Incandescent A-lamp on far right shown for size comparison)

DN83

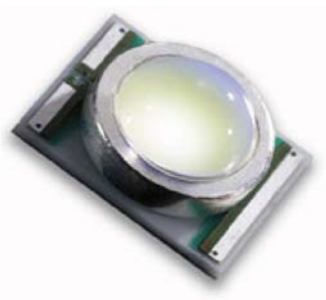
Description

This design note describes a driver solution developed using the Zetex ZXLD1350 LED driver IC to drive three CREE® XLamp XR-E High Brightness (HB) LEDs.

The **ZXLD1350** features can be summarized as:



- Wide input voltage range
- 7V to 30V; internal 30V NDMOS switch
- Up to 350mA output current (the ZXLD1360 can provide up to 1A output current)
- Capable of driving up to 8 series connected 1 Watt LEDs
- High efficiency (see datasheet - but >90% with 8 LEDs)
- Low quiescent current: (100μA typical)
- 1A max shutdown current
- Brightness control using DC voltage or PWM (low or high frequency)
- Internal PWM filter for high frequency PWM signals
- Optional soft-start; up to 1MHz switching frequency



The Cree **XR-E** LED is a lighting class device that provides energy savings for many traditional technologies such as the MR16 halogen lamp. The XR-E LED is capable of operating at forward currents of up to 1A without any noticeable shifts in chromaticity. The XR-E is ideally suited for direct replacement of MR16 when used in clusters of three at a forward current of 300mA—1000mA. They are specified at 80 lumens and 70 lumens per watt at 350mA (136 lumens at 700mA). These lighting class LEDs offer efficient, directional light that offers a lumen maintenance of 70% at 50,000 hours, in addition to significantly reducing power consumption.

The circuit diagram of the ZXLD1350 effected MR16 lamp solution is shown in *Figure 2*. *Table 1* provides the bill of materials. A full bridge (D1—D4) is employed using 1A DC rated, low leakage Schottky diodes to allow AC or DC input supplies. A thermistor circuit is incorporated to reduce the output current of the circuit to provide thermal feedback control, which allows the circuit to a) match the thermal de-rating requirements of the LEDs to ensure lumen maintenance expectations are achieved and b) prevent overheating. The thermistor must be thermally coupled to the LEDs to ensure accurate and responsive tracking. Adjustment of the thermal feedback circuit can be accomplished by the choice of the thermistor R3 - which sets the slope of the current vs. temperature response, and resistor R2 - which determines the temperature threshold point for the control circuit. R1 and D5 provide a reference voltage for the thermal control circuit. Q1 is a low $V_{CE(sat)}$ PNP transistor. Schottky diode D9 is again a low leakage 1A rated device in a SOT23 package - its low forward voltage and low reverse current ensure high efficiency and thermal stability in the main switching circuit. C3 may be added to reduce the amplitude of the current ramp waveform experienced by the LED string but in many applications this isn't required as the integrating nature of human sight cannot perceive quickly changing light levels. Depending on layout intricacies and EMC dictates, it may be necessary to exchange the positions of the inductor and LED string - this isn't always possible mechanically but does give a lower EMI signature.

Figure 3 shows the measured response of the LED current drive with respect to temperature, with the values given in *Table 2*. The selection of components for the thermal feedback circuit is not only dependent on the choice of R2 and R3, but also on the amount of heat sink area required to extract heat from the LEDs. To maximize the light output at high ambient or operating temperature conditions, the LEDs must have a sufficient thermal extraction path, otherwise the thermal control circuit will effect current drive reduction in non-optimal conditions. The thermal control threshold point is set by adjusting R2. For this design, three values (33k, 22k and 10k) were evaluated. These values were chosen to give break points at approximately 25°C, 40°C and 60°C. Note that the light output will not continually dim to zero - the thermal control is applying DC control to the ADJ pin and therefore has a dimming ratio from maximum current of approximately 5:1. Once the reduced DC level goes below the shutdown threshold of around 200mV, the LED drive current will fall to zero and the LEDs will be extinguished. The slope of the current reduction is determined by the beta value of the thermistor. The larger the beta value, the sharper will be the resultant current control response. The slope of the current reduction is also affected by Q1's base emitter voltage (V_{BE}) variation with temperature. *Figure 3* shows the slope starts to level off at higher temperatures due to the increasing influence of the approximately -2.2mV/°C change in the V_{BE} of the transistor.

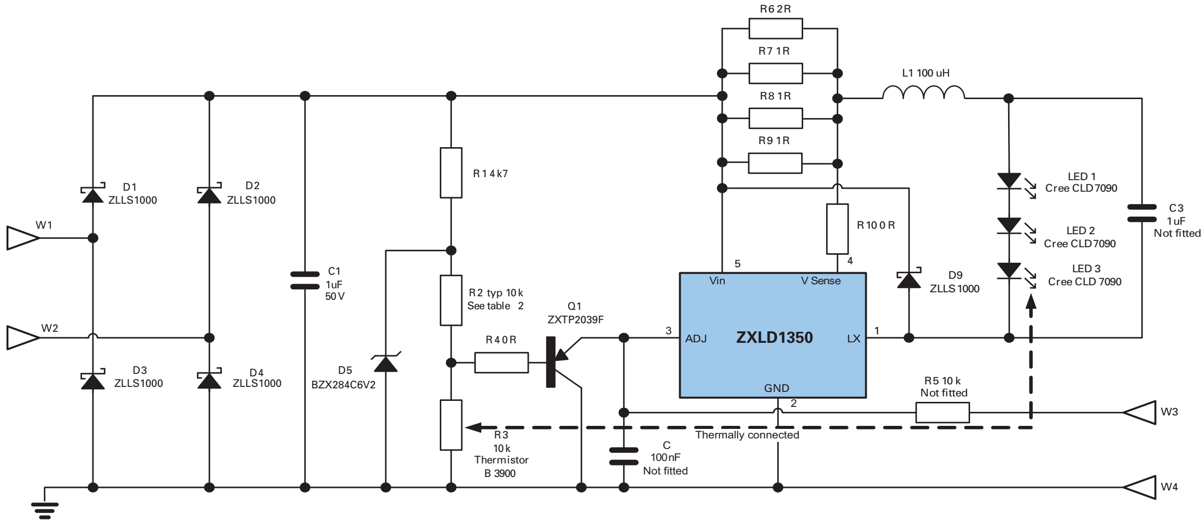


Figure 2 Circuit diagram of ZXLD1350 MR16 lamp solution

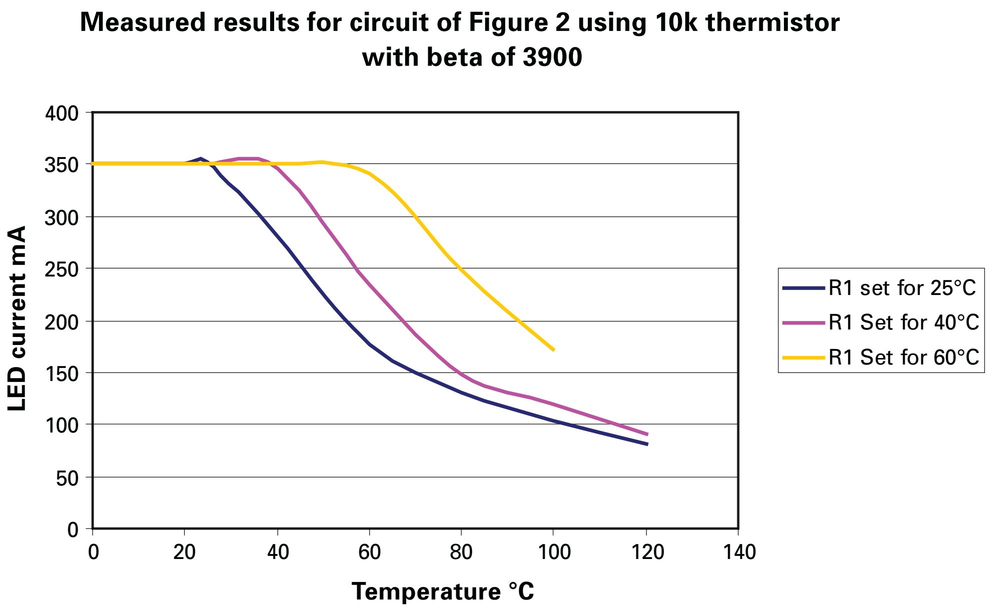


Figure 3 Measured response of thermal feedback control showing threshold point

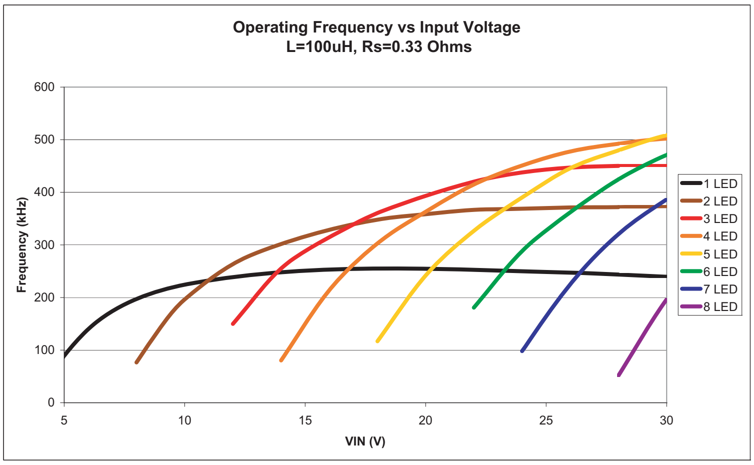
Quantity	Part reference	Value	Description	Source
1	R1	4k7	Resistor, 1%, 0603	Various
1	R2	See *Table 2* 0603 resistor	Resistor, 1% 0603	Various
1	R3	10K, 0603, Beta = ~3900 thermistor	Thermistor, 5% 0603	EPCOS
1	R4	0R, 0603 link	0R Link, 0603	Various
1	R5	10k, 0603 resistor	Generic	Various
1	R6	2R, 0603 resistor	Generic	Various
3	R7, R8, R9	1R, 0603 resistor	Generic	Various
	R10	0R 1206 link	0R Link, 1206	Various
5	D1, D2, D3, D4, D9	ZLLS1000	Schottky diode 40V, 1A	Zetex
1	D5	BZX284C6V2	6.2V Zener diode	
1	C1	1uF	Capacitor 50v 1206 X7R NMC1206X7R105K50F C1206C105K5RAC7800	NICcomponents KEMET
2	C2, C3		Not fitted	
3	LED1, LED2, LED3	XR-E	Cree XLamp power LED	Cree
1	Q1	ZXTP2039F	Transistor, PNP Alternative: FMMT717	Zetex
1	L1	100µH	MSS6132 100µH NPIS53D101MTRF	Coilcraft NIC components
1	IC1	ZXLD1350	Zetex LED driver IC	Zetex

Table 1 Bill of materials

Temp.	R2 = 33k R1 set for 25°C	R2 = 22k R1 set for 40°C	R2 = 10k R1 set for 60°C
0	350	350	350
20	350	350	350
25	352	350	350
40	280	345	350
60	177	235	342
80	131	148	248
100	104	120	171
120	81	90	

Table 2: Thermal feedback control threshold point (resistor R2)

For three series-connected LEDs, the voltage can be from 12V minimum to 30V DC maximum. For AC supplies, remember to include the 1.414 factor for RMS specified values - so for 20V AC (RMS), this will provide a DC rail after the Schottky bridge of 28.3V. The nominal current is set at 350mA with a 0.283Ω sense resistor. The sense resistor is a combination component using 4 low cost, commonly available values and allows current set point flexibility if the circuit is used as a platform design for a series of products. For three series-connected LEDs, with a nominal supply of 24V and a 100μH inductor, the ZXLD1350 runs in continuous mode at approximately 500kHz. The ZXLD1350 datasheet displays this information graphically, as shown in Figure 4 (for a sense resistor of 330mΩ in this case), which allows a fast assessment to be made of operating conditions. The switching frequency will increase as the voltage on the ADJ pin decreases. As the ZXLD1350 (and ZXLD1360) series of LED drivers use a hysteretic switching topology, the switching frequency is dependent on several factors - input voltage, target current (including any effect by voltage on the ADJ pin to reduce the current) and number of LEDs. An Excel based calculator is available which allows "what-if" initial evaluation and is a useful tool for assessing component and condition changes. Final designs should, of course, be verified by reality.



Note: Please see the ZXLD1350 datasheet for complete characterization including efficiency, duty cycle and current variation charts for various values of inductor

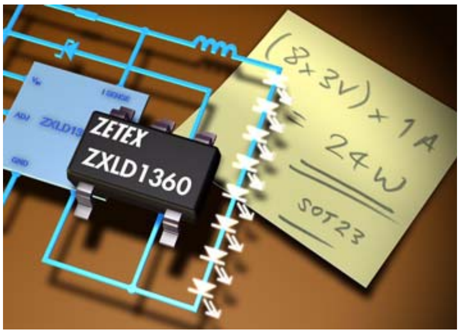
Figure 4 Example of operating frequency chart for the ZXLD1350

DN83

Higher current designs

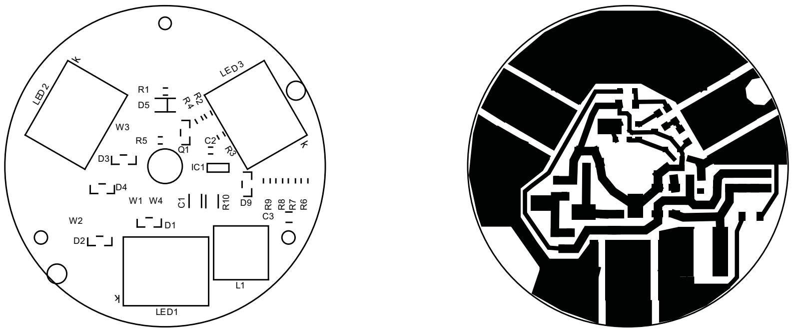
The ZXLD1350 is designed for LED current drive applications of up to 350mA. The monolithic N-MOSFET is sized appropriately to provide a cost-effective die size and is rated to 400mA, which with the hysteretic mode of operation (the current waveform will ramp ±15% about the nominal current set point) provides sufficient margin. For higher current operation, the 1A rated **ZXLD1360** offers similar design procedures and has the following features:

- Up to 1A output current
- Wide input voltage range: 7V to 30V
- Internal 30V 400m NDMOS switch
- Can drive up to 7 series connected 3W LEDs (with due attention to thermal path design)
- High efficiency (>90% for 7 LEDs)
- Brightness control using DC voltage or PWM
- Internal PWM filter
- Optional soft-start
- Up to 1MHz switching frequency



Board design

The Printed Circuit Board (PCB) design and circuit employed make it particularly suitable for use in MR16 halogen lamp replacement units. The supply voltage range is nominally 12V AC or DC, making it compatible and interchangeable with existing MR16 lamps. The printed circuit tracking has been designed using only one side of the board, to facilitate the use of an aluminum or other heat-conductive substrate where through-hole technology cannot be employed. A central hole is provided to enable connection of the supply leads from the rear and for connection to a dimming circuit, where this is required. Mounting holes are also provided. Gerber-format layout files for this PCB are available from Zetex upon request. Please quote PCB number ZDB335.



Top PCB overlay

Top copper

Figure 5 Top PCB overlay and top copper

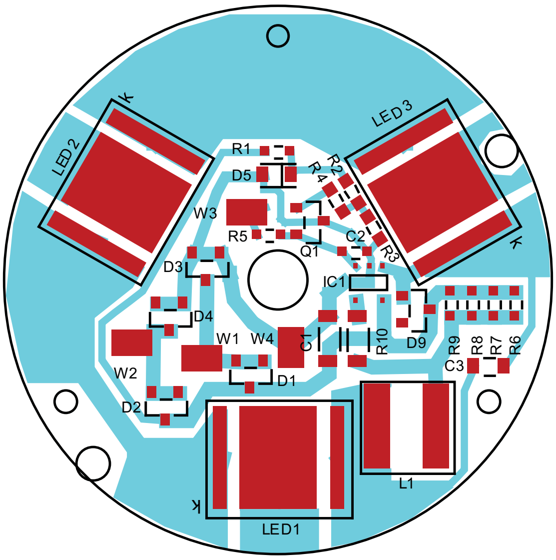


Figure 6 Composite view

Appendix A - ZXLD1350 operation

In normal operation, when voltage is applied at $+V_{CC}$, the ZXLD1350 internal NDMOS switch is turned on. Current starts to flow through the sense resistor, inductor L1, and the LEDs. The current ramps up linearly, and the ramp rate is determined by the input voltage $+V_{CC}$ and the inductor L1. This rising current produces a voltage ramp across the sense resistor. The internal circuit of the ZXLD1350 senses the voltage across the sense resistor, and applies a proportional voltage to the input of the internal comparator. When this voltage reaches an internally set upper threshold, the NDMOS switch is turned off. The inductor current continues to flow through the sense resistor, L1, the LEDs, the Schottky diode SD9, and back to the supply rail, but it decays, with the rate of decay determined by the forward voltage drop of the LEDs and the Schottky diode. This decaying current produces a falling voltage at the sense resistor, which, in turn, is sensed by the ZXLD1350. A voltage proportional to the sense voltage across the sense resistor is applied at the input of the internal comparator. When this voltage falls to the internally set lower threshold, the NDMOS switch is turned on again. This switch-on-and-off cycle continues to provide the average LED current set by the sense resistor.

Both DC and PWM dimming can be achieved by driving the ADJ pin through W3. For DC dimming, the ADJ pin may be driven between 300mV and 1.25V. Driving the ADJ pin below 200mV will shutdown the output current. For PWM dimming, an external open-collector NPN transistor or open-drain N-channel MOSFET can be used to drive the ADJ pin. The PWM frequency can be low, around 100Hz to 300Hz, or high between 10kHz to 50kHz. For the latter case, an on-chip filter derives the DC content and so for high frequency PWM input, the device will operate essentially as for DC control input dimming. Generally, low frequency PWM control is preferred as in this mode, the converter is shut down during PWM low signals and drives the LEDs at the defined nominal current during PWM high signals - this ensures that the LEDs can are always driven at the nominal current and therefore color temperature (CCT) shifts are minimized. The capacitor C2 should be around 10nF to decouple high frequency noise at the ADJ pin for DC dimming. Note - C2 should not be fitted when using the PWM dimming feature. The soft-start time will be nominally 0.5ms without capacitor C2. Adding C2 will increase the soft start time by approximately 0.5ms/nF

Please refer to the datasheets for the threshold limits, ZXLD1350 internal circuits, electrical characteristics and parameters.

DN84
ZXSC400 Driving 3W high power LEDs

Ray Liu, Applications Engineer, Zetex Semiconductors

Description

This design note shows the ZXSC400 driving a single 3W LED. The input voltage ranges from 1.8V to 3.6V with constant output current of 700mA down to 2.6V with an overall 80% of efficiency.

Figure 1 shows typical constant current solution with ZXSC400 driving one 3W LED. The input voltage range allows the use of two alkaline batteries or one Lithium Ion cell (CR123A) for portable flashlight applications.

Q1 and Q2 forms a pseudo Darlington pair which provide enough current gain for a switching current up to 1.5A. In order to provide better switch off performance, a Schottky diode, D2, is used to drain the base current from the base of Q1 directly. In order to achieve higher efficiency, current monitor U2 is used to provide a low voltage drop LED current sensing through the low ohmic resistor, R2. The LED current is converted to 300mV feedback voltage through R3.

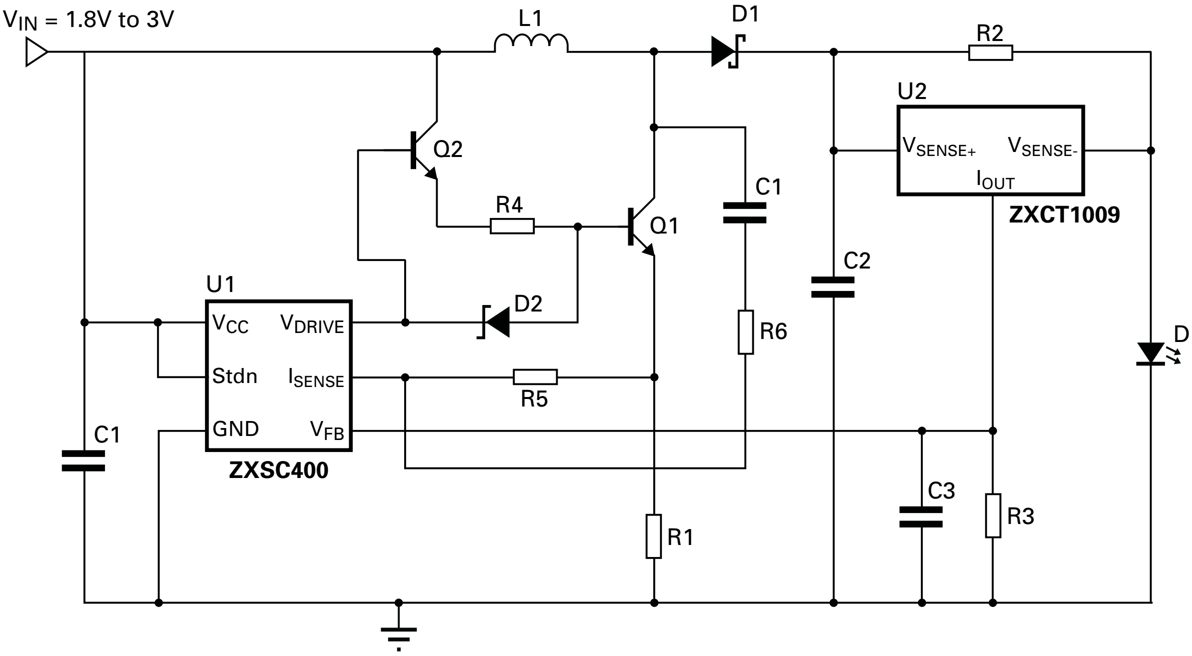


Figure 1   Schematic diagram

Ref.	Value	Part number	Manufacturer	Comments
U1		ZXSC400E6	Zetex	LED driver in SOT23-6
U2		ZXCT1009	Zetex	Current monitor in SOT23
Q1		ZXTN25012EFH	Zetex	Low sat NPN in SOT23
Q2		ZXTN25012EFL	Zetex	Low sat NPN in SOT23
D1		ZHCS2000	Zetex	2A Schottky in SOT23
D2		ZHCS400	Zetex	400mA Schottky
L1	15μH	744 561 15	Wurth Electronik	ISAT = 3A DCR=60mΩ
R1	20mΩ 1%	Generic	Generic	0805 size low ohmic
R2	50mΩ 1%	Generic	Generic	0805 size low ohmic
R3	820Ω 1%	Generic	Generic	0805 size
R4	82Ω 5%	Generic	Generic	0805 size
R5	4.7Ω 5%	Generic	Generic	0805 size
R6	10Ω 5%	Generic	Generic	0805 size
C1	22μF 10V 10%	Generic	Generic	1206 size X7R/X5R
C2	4.7μF 10V 10%	Generic	Generic	1206 size X7R/X5R
C3	0.22μF 16V			
10%	Generic	Generic		
C4	330pF/10V	Generic	Generic	0805 size

Table 1 Bill of materials

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Typical operating characteristics

(For typical application circuit where T_{amb} = 25°C unless otherwise stated)

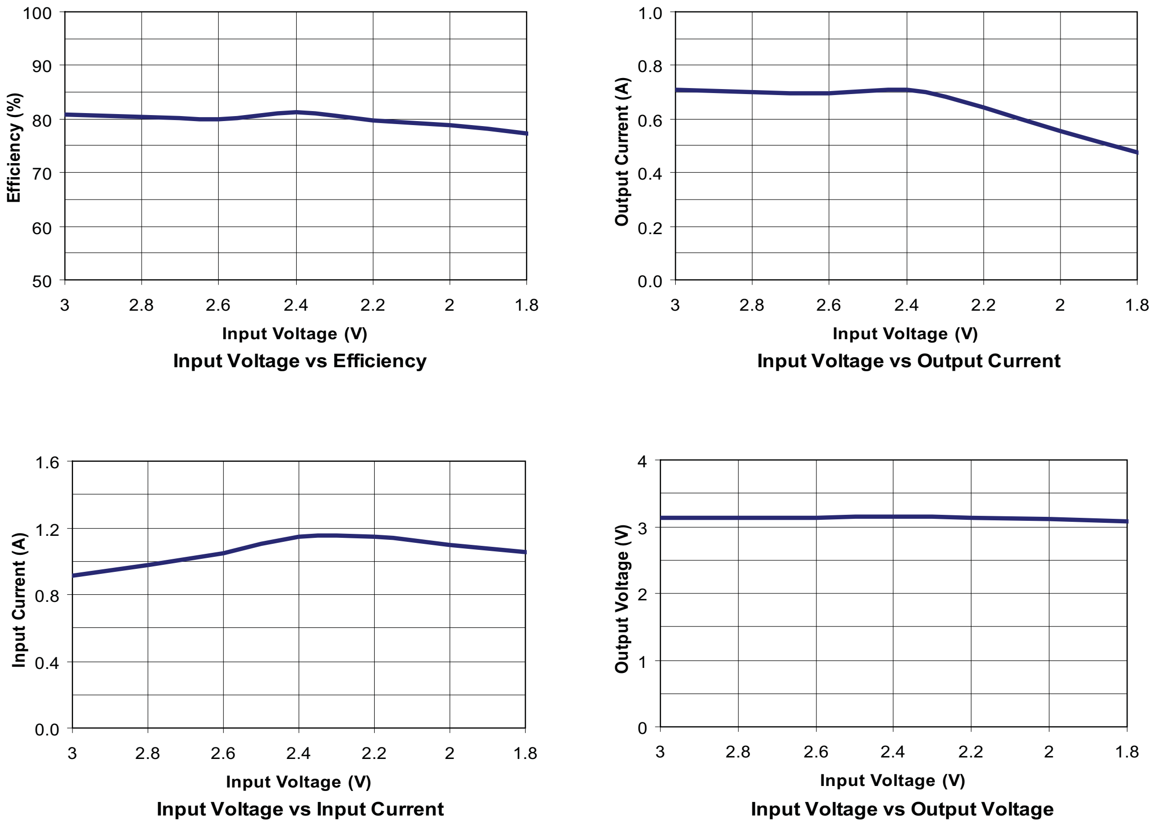

Figure 2 Performance graphs

DN85
ZXSC400 1W/3W buck LED drivers

Ray Liu, Applications Engineer, Zetex Semiconductors

Description

In Figure 1, ZXSC400 is configured as a high efficiency buck LED driver. The target applications are either 1W (350mA) or 3W (700mA) drivers for white LED driven from a 4 cell battery, or a 2 alkaline cell input for flashlights. The supply voltage for ZXSC400 reference design is:

V_{IN} = 3.8V to 6V.

Parts lists for 1W and 3W design are shown in Table 1 and Table 2 respectively. Performance data is measured based on two different LED's V_F binning with 0.3V V_F difference.

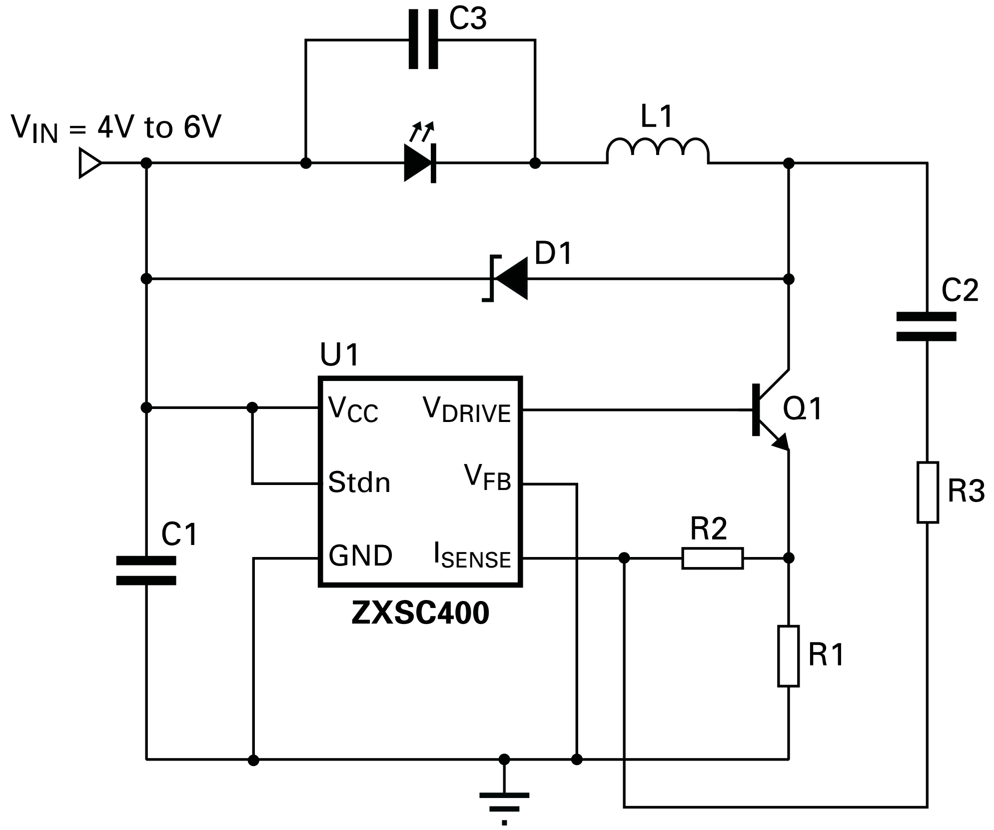

Figure 1 Schematic diagram

Ref.	Value	Package	Part number	Manufacturer	Contact details	Notes
U1	N/A	SOT23-6	ZXSC400E6	Zetex	www.zetex.com	LED Driver
Q1	N/A	SOT23	ZXTN25012EFL	Zetex	www.zetex.com	Low sat NPN transistor
D1	40V/0.75A	SOT23	BAT750	Zetex	www.zetex.com	40V/0.75A Schottky diode
L1	47μH	N/A	744052470	Wurth Elektronik	www.we-online.com	I_{SAT} = 520mA
R1	62mΩ	0805		Generic	N/A	0805 1%
R2	10Ω	0805		Generic	N/A	0805 5%
R3	47Ω	0805		Generic	N/A	0805 5%
C1	4.7μF/10V	1206		Generic	N/A	X7R/X5R
C2	100pF/10V	0805		Generic	N/A	COG/NPO
C3	1uF/10V	0805		Generic	N/A	X7R/X5R optional

Table 1 Bill of materials for 1W LED

Performance

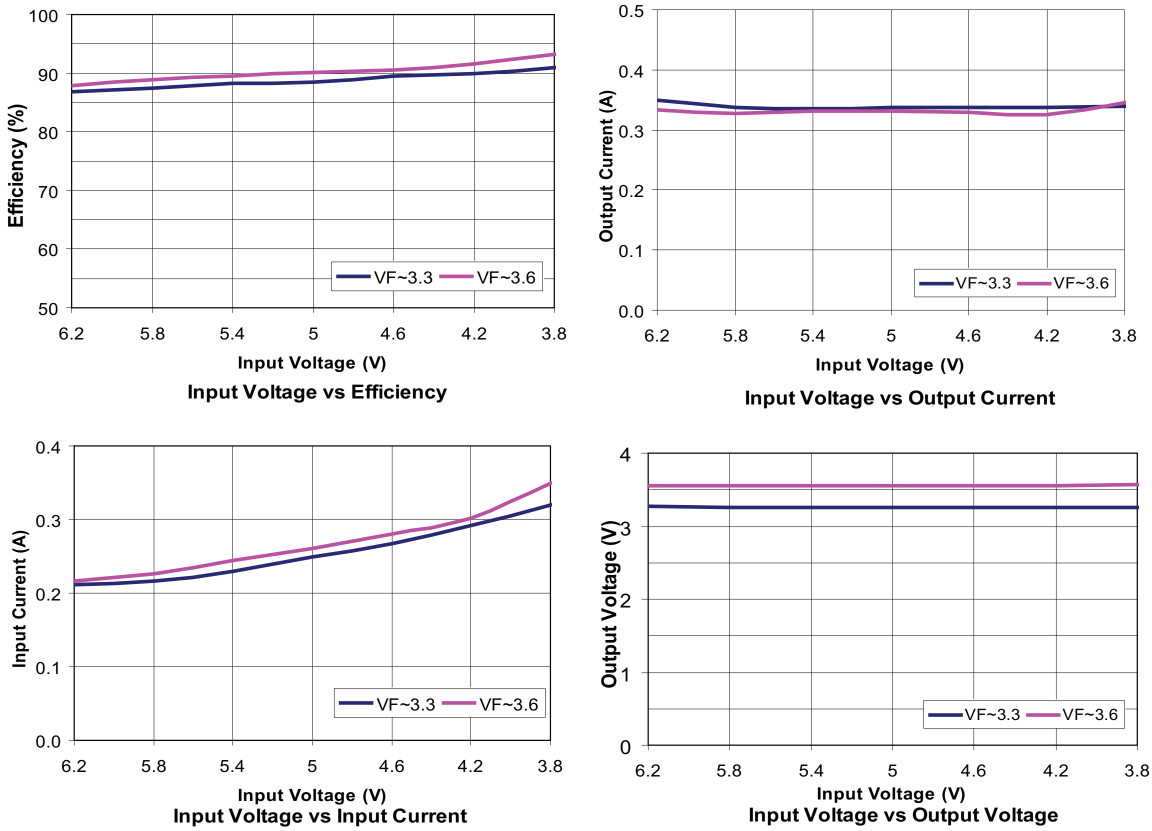

Figure 2 Performance graphs for 1W design

Ref.	Value	Package	Part number	Manufacturer	Contact details	Notes
U1	N/A	SOT23-6	ZXSC400E6	Zetex	www.zetex.com	LED Driver
Q1	N/A	SOT23	ZXTN25012EFL	Zetex	www.zetex.com	Low sat NPN transistor
D1	40V/1A	SOT23	ZHCS1000	Zetex	www.zetex.com	40V/1A Schottky diode
L1	33μH	N/A	722065330	Wurth Elektronik	www.we-online.com	Isat=1.6A
R1	30mΩ	0805		Generic	N/A	0805 1%
R2	10Ω	0805		Generic	N/A	0805 5%
R3	47Ω	0805		Generic	N/A	0805 5%
C1	10μF/10V	1210		Generic	N/A	X7R/X5R
C2	100pF/10V	0805		Generic	N/A	COG/NPO
C3	2.2uF/10V	1206		Generic	N/A	X7R/X5R optional

Table 2 Bill of materials for 3W LED

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DN85

Performance

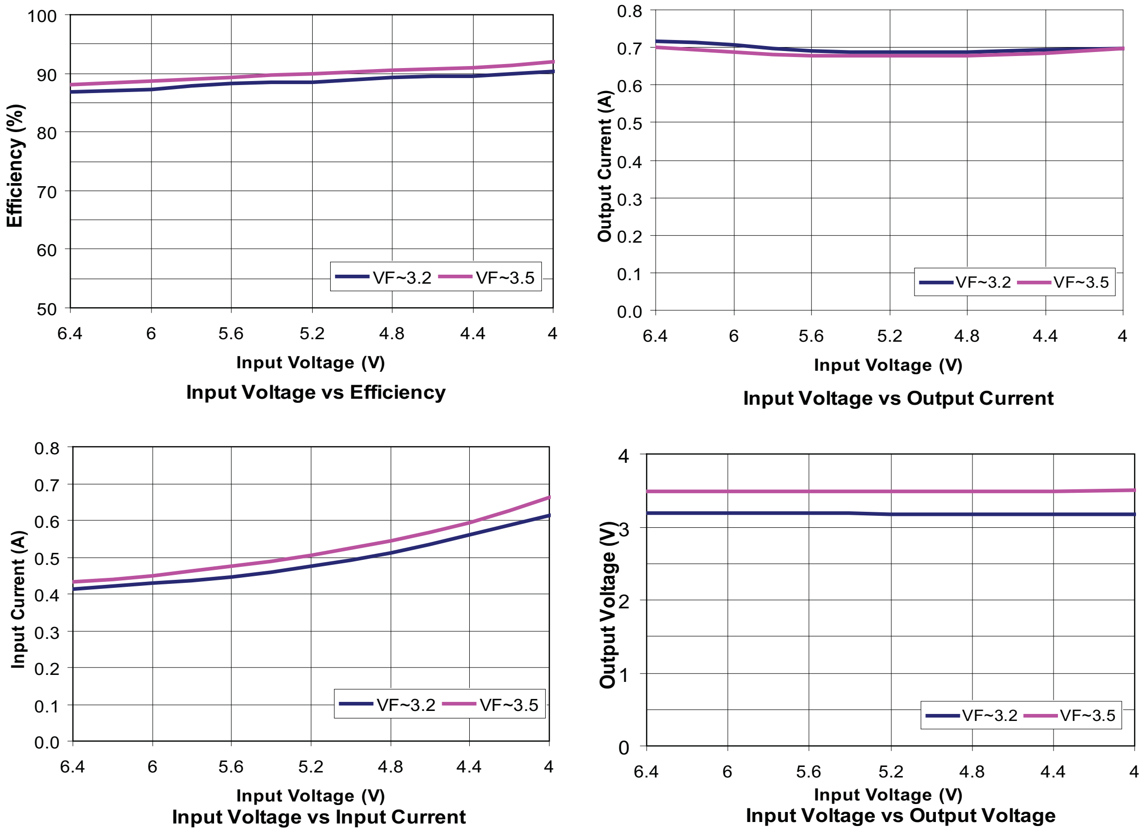


Figure 3 Performance graphs for 3W design

DN86
Reduced component count and compact reference design for MR16 replacement lamps using multiple 1W LEDs

Silvestro Russo, October 2007

Introduction

MR16 lamps are one variety of Multifaceted Reflector (MR) lamps that usually employ a halogen filament capsule as the light source. They are used in many retail and consumer lighting applications where their size, configurability, spot-lighting capability and aesthetics provide utility and creativity. Low efficiency, heat generation and halogen capsule handling issues are among the disadvantages of the technology. They typically operate from 12V DC or 12V AC, using conventional electromagnetic transformers.

LEDs offer a more energy efficient and no radiated heat solution to replace some halogen lamp applications.

This reference design is intended to fit into the base connector space of an MR16 style LED lamp. The design has been optimized for part count and thermal performance. The design can be used with up to 3 1W LEDs in the Lens section. This can be arranged to suit the luminary designer's requirements.

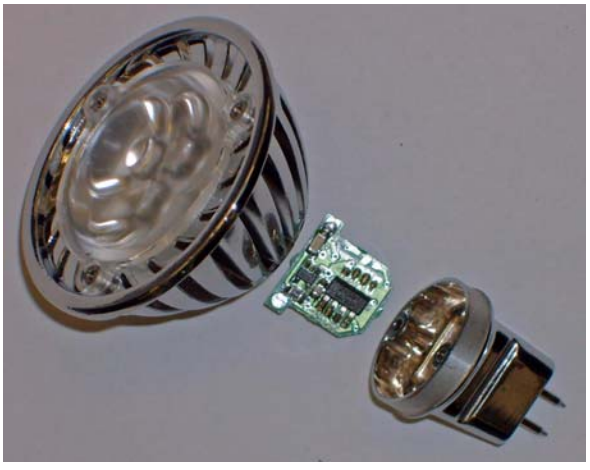
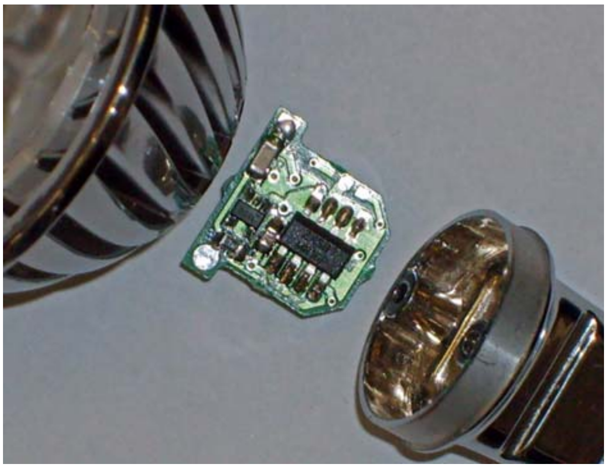



Figure 1 MR16 application with ZXLD1350

Data sheet

It is recommended that this design note is used with the data sheet for the ZXLD1350 see http://www.zetex.com/3.0/pdf/ZXLD1350.pdf

Description

The system diagram of the MR16 lamp solution with ZXLD1350 and ZXSBMR16PT8 is shown in Figure 2, and Table 1 provides the bill of materials.

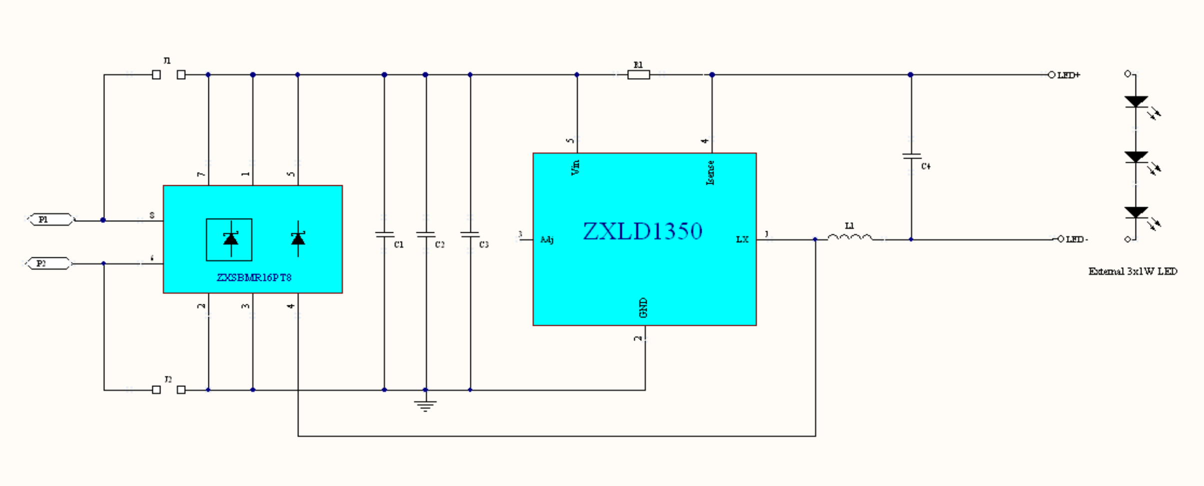


Figure 2 System diagram of ZXLD1350 MR16 Lamp Solution

The **ZXLD1350** is designed for LED current drive applications of up to 350mA. The monolithic NMOSFET is sized appropriately to provide a cost-effective die size and is rated to 400mA, which with the hysteretic mode of operation (the inductor current waveform will ramp +/-15% about the nominal current set point) provides sufficient margin. The main features of the ZXLD1350 are:

- Up to 380mA output current
- Wide input voltage range: 7V to 30V
- Internal 30V 400mA NDMOS switch
- High efficiency (>90% possible)
- Up to 1MHz switching frequency

The **ZXSBMR16PT8** is a new space saving and thermally efficient device specifically designed for the critical requirements of MR16 applications. The device encompasses a full bridge and a freewheeling diode realized using extremely low leakage 1A, 40V Schottky diodes to allow a nominal 12V AC input operations. The Schottky bridge together with the embedded freewheeling diode enhance the system efficiency compared to the standard silicon diodes in a compact format. The reference design has solder tag pins to bypass the bridge rectifier should the final lamp design be used for purely DC operation.

As the ZXLD1350 has a hysteretic switching topology, the switching frequency is dependent on several factors - input voltage, target current and number of LEDs. An Excel based calculator is available for system initial evaluation and component choice.

See http://www.zetex.com/3.0/otherdocs/zxld1350calc.xls

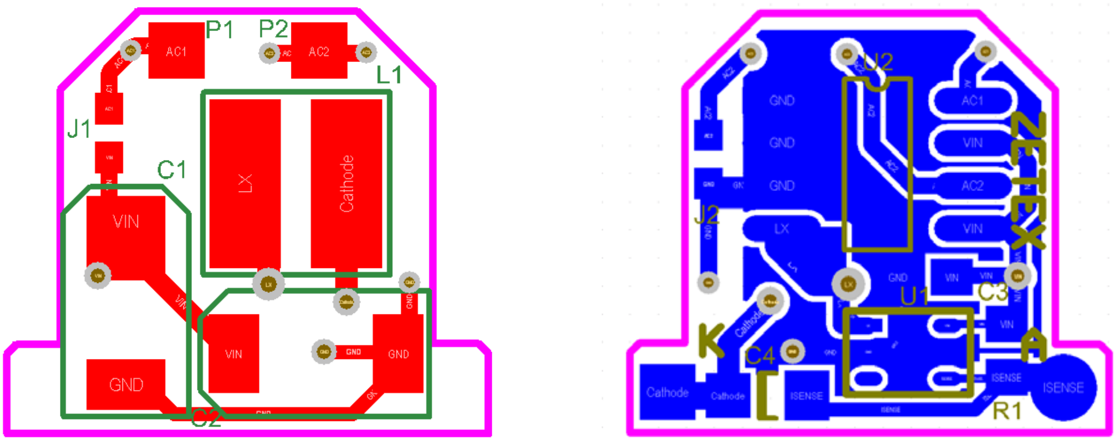
System efficiency and LED current have been measured keeping the ADJ pin floating and the current in the device at its rated value. The input impedance of the ADJ pin is high (200K) and is susceptible to leakage currents from other sources. Anything that sinks current from this pin will reduce the output current. In order to avoid any kind of electromagnetic coupling a guard track around this pin is used.

Quantity	Part reference	Value	Description	Source
1	R1	0.33Ω	Resistor, 1%, 0805	Various
2	C1, C2	150µF/20V	Type D SMD Tantalum Cap	Kemet
1	C3	0.1µF/25V	SMD 0805 X7R	NIC Components
1	C4	1µF/25V	SMD 1210 X7R	NIC Components
1	L1	100µH	MSS6132-104	Coilcraft
1	U1	ZXLD1350	LED driver IC	ZETEX
1	U2	ZXSBMR16PT8	Schottky bridge rectifier and freewheeling diode	ZETEX

Table 1 Bill of Material

Referring to circuit schematic in Figure 2; the jumper connection could be used utilizing a zero ohm resistor, in order to enable the pure DC operations.
Care has to be taken in this case, since the system is not reverse polarity protected.

In Figure 3 the circuit layout is shown, highlighting its space saving features and compactness. Both bottom layer and top layer are shown to display effective devices arrangement.



TOP COPPER AND SILKSCREEN **BOTTOM COPPER AND SILK SCREEN**

Figure 3 Circuit layout

The main layout design suggestions are:

- All thin devices on one side
- Employ a star connection for ground tracks
- Use a ground ring protecting ADJ pin
- Check that:
  - Tracks connecting R1 to ZXLD1350 are as short as possible (being sense tracks)
  - The filter capacitor C3 is connected as close as possible to the V_{in} pin
  - The freewheeling current path is as short as possible to ensure system precision and efficiency

Circuit board views

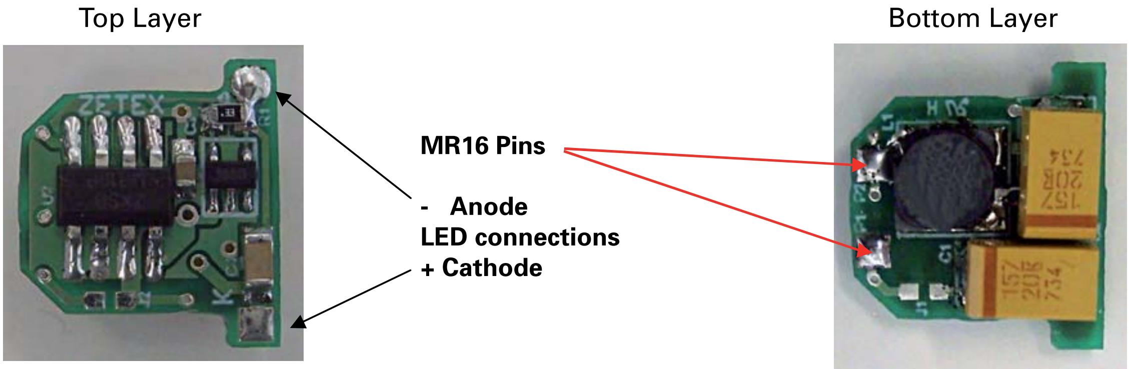


Figure 4 Circuit board views

Choice of Inductor and switching circuit layout

A 100 μH screened inductor was chosen to set the nominal frequency around 250kHz. A screened inductor is chosen to minimize radiated EMI. The layout with any switching regulator is crucial to minimize radiated EMI. This reference design keeps the critical track lengths to a minimum. Ground areas have been maximized around critical areas.

Circuit performances

Circuit performances have been evaluated taking into account two main parameters, the system efficiency and the current precision.

The reference current is set to a nominal 300mA but can be adjusted to any value up to 350mA by changing the sense resistor R_{sense} according to the formula:

$$I_{ref} = 0.1/R1 \qquad [A]$$

$$\text{For} \qquad R1 = 0.33\Omega \quad \rightarrow \quad I_{ref} = 300mA$$

In Table 2 the data related to the system supplied with a DC voltage ranges from 12V to 15V. For these tests the Schottky bridge was included. The most important parameters are the system efficiency and the error between the rated LED current (300mA) and the actual LED current. In the DC case the frequency ranges between 150kHz and 300kHz, depending on the input voltage. Whatever the input voltage, the efficiency is higher than 87% and the error lower than 2%.

Vin [V]	Iin[A]	Vout[V]	Iout[A]	Efficiency	Current Accuracy
12.000	0.275	9.80	0.296	87,9%	1.3%
13.000	0.252	9.78	0.294	87.7%	2.0%
14.000	0.232	9.76	0.294	87.6%	2.0%
15.000	0.220	9.75	0.294	87.4%	2.0%

Table 2 DC input voltage

Table 3 shows the data related to the system supplied with an AC electromagnetic transformer. Using a SMD tantalum capacitor will save space and avoid using a larger aluminum electrolytic capacitor. This will improve the reliability of the system and stabilize performance during its lifetime. There is a trade off between physical size, reliability, cost and average LED current. Typical output voltages from a nominal 12V AC transformer can be ±10%. With 3 LEDs the voltage across these will be around 10V. If the input capacitor value is lower then 200μF, the AC input waveform is distorted (as can be seen in figure 8). When the rectified AC is not sufficiently smoothed the ripple may drop below the combined LED forward voltage which stops the switching regulator and so reduces the average current in the LEDs. This will also reduce the average lumens output.

C1 [µF]	Vin [V]	Iin[A]	Vout[V]	Iout[A]	Efficiency	Current Accuracy
100	12.70	0.303	9.28	0.225	54%	25%
150	12.60	0.394	9.50	0.271	52%	10%
200	12.53	0.432	9.55	0.293	52%	2%
300	12.50	0.386	9.70	0.295	60%	2%

Table 3 AC input voltage

Figures 5 to 7 show the input voltage ripple and LX voltage varying the input capacitance value C_{in} = C1 + C2 + C3. The higher the input capacitance the higher to output current precision and the average lumens outputs. The case with C_{in}=300µF has the best performance both as efficiency and current precision. Reducing the input capacitance the output current precision will decrease up to 25% with system efficiency always above 50%.

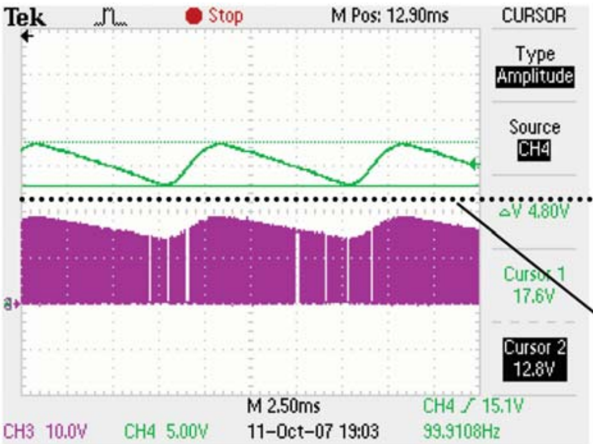


Figure 5 C_{in}=300µF

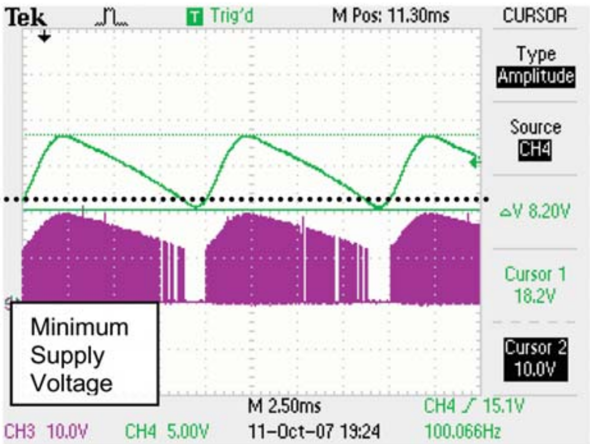


Figure 6 C_{in}=200µF

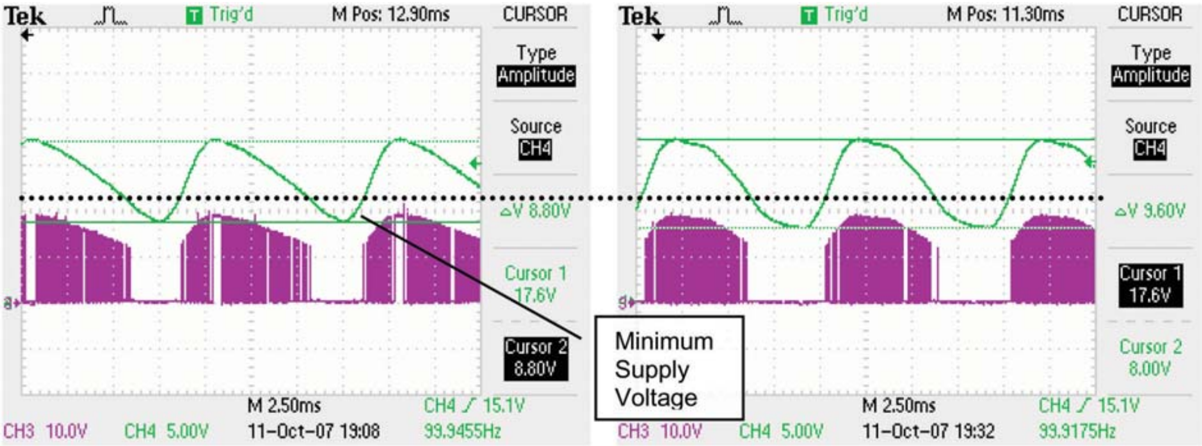


Figure 7 C_{in}=150µF **Figure 8 C_{in}=100µF**

Figure 5 to 8: input ripple and LX voltage (Ch3 is the LX pin voltage and Ch4 is the input voltage)

Gerber plots and further assistance are available from your local Zetex contact or Distributor. You can contact your local sales office by email.

europe.sales@zetex.com

usa.sales@zetex.com

asia.sales@zetex.com

Conclusion

A compact, reliable, efficient and minimum part count solution can be realized using the ZXLD1350, ZXSBMR16PT8, and associated passive components. The compact design in the connector housing keeps the temperature sensitive semiconductors as far from the heat generating LEDs as possible. A compromise between LED current and size of capacitance is necessary for the final solution which accounts for efficiency, accuracy, size, and component count.

This is the first design note in a series of reference designs MR16 variants solutions and options.

SEMICONDUCTORS

AN44
A high power LED driver for low voltage halogen replacement

Introduction

LED lighting is becoming more popular as a replacement technology for Halogen low voltage lighting, primarily because of the low efficiency, reliability and lifetime issues associated with Halogen bulbs.

Discussed below is a novel approach for driving high power LED's as a replacement for low voltage halogen lighting systems.

A typical schematic diagram is shown in Figure 1.

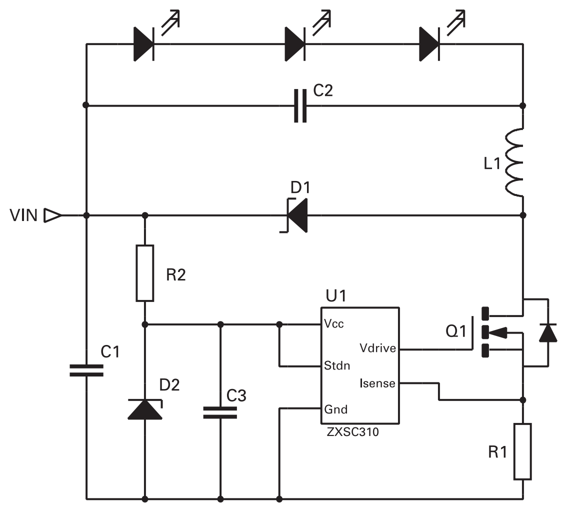


Figure 1 Schematic diagram

Operation

Please refer to the typical schematic diagram in Figure 1.

On period, T_{ON}

The ZXSC300 turns on Q1 until it senses 19mV (nominal) on the I_{SENSE} pin.

The current in Q1 to reach this threshold is therefore 19mV/R1, called I_{PEAK}.

With Q1 on, the current is drawn from the battery and passes through C1 and LED in parallel. Assume the LED drops a forward voltage V_F. The rest of the battery voltage will be dropped across L1 and this voltage, called V(L1) will ramp up the current in L1 at a rate di/dt = V(L1)/L1, di/dt in Amps/sec, V(L1) in volts and L1 in Henries.

The voltage drop in Q1 and R1 should be negligible, since Q1 should have a low $R_{DS(on)}$ and R1 always drops less than 19mV, as this is the turn-off threshold for Q1.

$V_{IN} = V_F + V(L1)$

$T_{ON} = I_{PEAK} \times L1/ V(L1)$

So T_{ON} can be calculated, as the voltage across L1 is obtained by subtracting the forward LED voltage drop from V_{IN}. Therefore, if L1 is smaller, T_{ON} will be smaller for the same peak current I_{PEAK} and the same battery voltage V_{IN}. Note that, while the inductor current is ramping up to I_{PEAK}, the current is flowing through the LED and so the average current in the LED is the sum of the ramps during the T_{ON} ramping up period and the T_{OFF} ramping down period.

Off period, T_{OFF}

The T_{OFF} of ZXSC300 and ZXSC310 is fixed internally at nominally 1.7µs. Note that, if relying on this for current ramp calculations, the limits are 1.2µs min., 3.2µs max.

In order to minimize the conductive loss and switching loss, T_{ON} should not be much smaller than T_{OFF}. Very high switching frequencies cause high dv/dt and it is recommended that the ZXSC300 and 310 are operated only up to 200 kHz. Given the fixed T_{OFF} of 1.7µs, this gives a T_{ON} of (5µs - 1.7µs) = 3.3µs minimum. However, this is not an absolute limitation and these devices have been operated at 2 or 3 times this frequency, but conversion efficiency can suffer under these conditions.

During T_{OFF}, the energy stored in the inductor will be transferred to the LED, with some loss in the Schottky diode. The energy stored in the inductor is:

½ x L x I_{PEAK}2 [Joules]

Continuous and discontinuous modes (and average LED current)

If T_{OFF} is exactly the time required for the current to reach zero, the average current in the LED will be I_{PEAK}/2. In practice, the current might reach zero before T_{OFF} is complete and the average current will be less because part of the cycle is spent with zero LED current. This is called the 'discontinuous' operation mode and is shown in Figure 2.

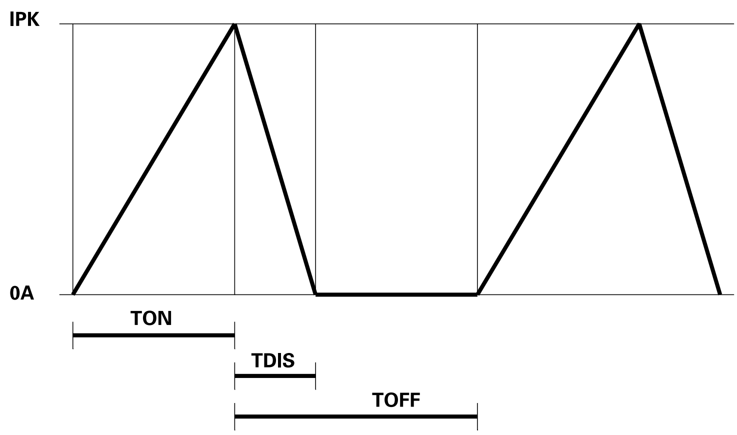


Figure 2

For continuous mode

If the current does not reach zero after 1.7µs, but instead falls to a value of I_{MIN}, then the device is said to be in 'continuous' mode. The LED current will ramp up and down between I_{MIN} and I_{PEAK} (probably at different di/dt rates) and the average LED current will therefore be the average of I_{PEAK} and I_{MIN}, as shown in Figure 3.

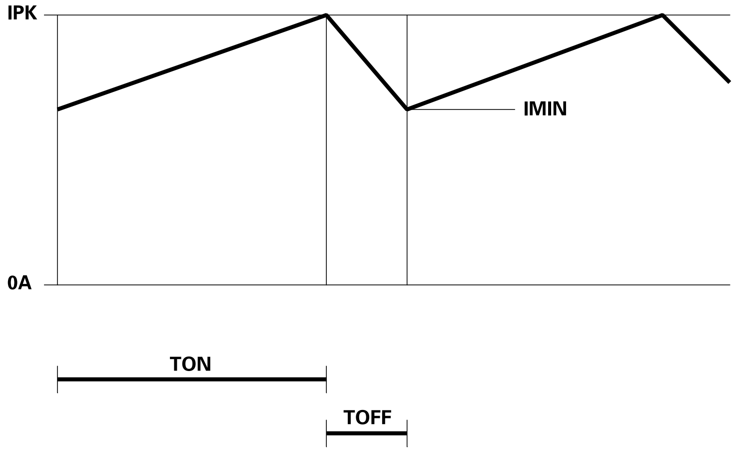


Figure 3

Design example

(Refer to Figure 1 and Table 1)

Input = V_{IN} = 12V

LED forward drop = V_{LED} = 9.6V

$V_{IN} = V_{LED}+V_L$

Therefore V_L = (12 - 9.6) = 2.4

The peak current = V_{SENSE} / R1

(R1 is R_{SENSE}) = 24mV/50mR = 480mA

$T_{ON} = I_{PEAK} \times L1/V(L1)$

$$T_{ON} \frac{680mA x 22\mu H}{2.4} = 6.2\mu s$$

These equations make the approximation that the LED forward drop is constant throughout the current ramp. In fact it will increase with current, but they still enable design calculations to be made within the tolerances of the components used in a practical circuit. Also, the difference between V_{IN} and V_{LED} is small compared to either of them, so the 6.2µs ramp time will be fairly dependent on these voltages.

Note that, for an LED drop of 9.6V and a Schottky drop of 300mV, the time to ramp down from 680mA to zero would be:

$$TDIS \frac{680mA x 22\mu H}{(9.6 + 0.3)} = 1.5\mu s$$

As the T_{OFF} period is nominally 1.7μs, the current should have time to reach zero. However, 1.5μs is rather close to 1.7μs and it is possible that, over component tolerances, the coil current will not reach zero, but this is not a big issue as the remaining current will be small. Note that, because of the peak current measurement and switch-off, it is not possible to get the dangerous ‘inductor staircasing’ which occurs in converters with fixed T_{ON} times. The current can never exceed I_{PEAK}, so even if it starts from a finite value (i.e. continuous mode) it will not exceed the I_{PEAK}. The LED current will therefore be approximately the average of 680mA and zero = 340mA (it will not be exactly the average, because there is a 200ns period at zero current, but this is small compared with the I_{PEAK} and component tolerances).

Ref	Value	Part number	Manufacturer	Contact details	Comments
U1		ZXSC310E5	Zetex	www.zetex.com	LED Driver in SOT23-5
Q1		ZXMN6A07F	Zetex	www.zetex.com	N-channel MOSFET in SOT23
D1	1A / 40V	ZHCS1000	Zetex	www.zetex.com	1A Schottky diode in SOT23
D2	6V8	Generic	Generic		6V8 Zener diode
L1	22μH	DO3316P-223	Coilcraft	www.coilcraft.com	
R1	50mΩ	Generic	Generic		0805 size
R2	1k2Ω	Generic	Generic		0805 size
C1	100μF/25V	Generic	Generic		
C2	1μF/10V	Generic	Generic		
C3	2.2μF/25V	Generic	Generic		

Table 1 Bill of materials

Typical performance graphs for 12V system

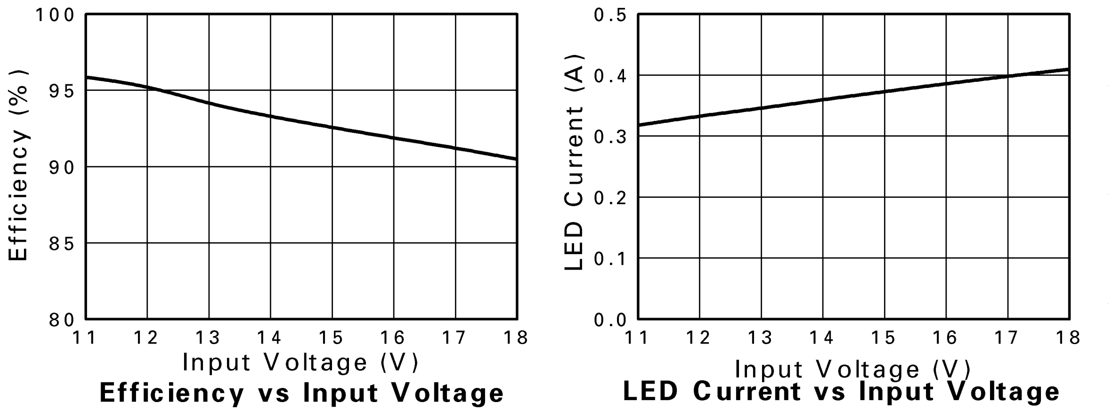


Figure 4 Performance graphs for 12V system

By changing the value of R2 from 1k2Ω to 2k2Ω the operating input voltage range can be adjusted from 30V to 20V, therefore the solution is able to operate from the typical operating voltage supplies of 12V and 24V for low voltage lighting.

Typical performance graphs for 24V system

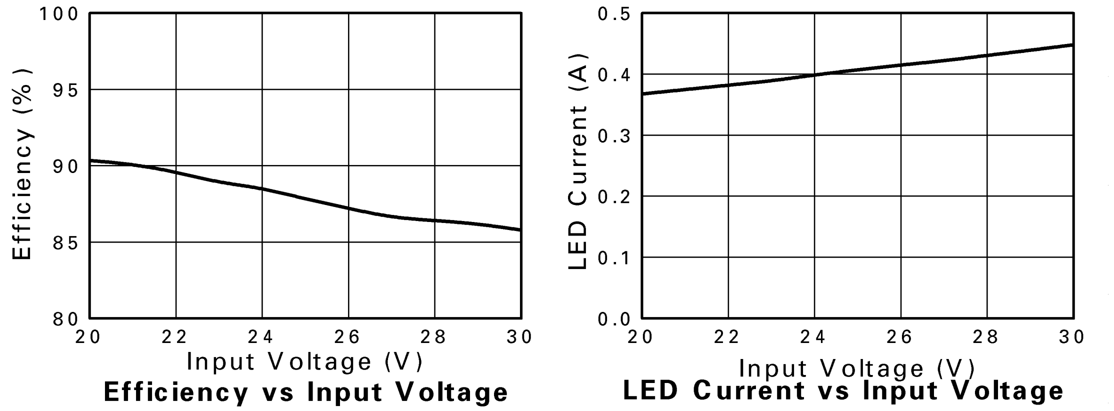


Figure 5 Performance graphs for 24V system

Useful formulae for calculations

The input power from the battery during TON (assuming discontinuous operation mode) is V_{IN} * I_{PEAK}/2. The average input current from the battery is therefore this current multiplied by the ratio of T_{ON} to the total cycle time:

$$\frac{I_{PEAK}}{2} \times \frac{T_{ON}}{T_{ON} \times T_{OFF}}$$

It can be seen from this how the average battery current will increase at lower V_{IN} as T_{ON} becomes larger compared to the fixed 1.7µs T_{OFF}. This is logical, as the fixed (approximately) LED power will require more battery current at lower battery voltage to draw the same power.

The energy which is stored in the inductor equals the energy which is transferred from the inductor to the LED (assuming discontinuous operation) is:

½ * L1 * I_{PEAK}^2 [Joules]

$$T_{ON} = \frac{I_{PEAK} \times L1}{(V_{BATT} - V_{LED})}$$

Therefore, when the input and the output voltage difference are greater, the LED will have more energy which will be transferred from the inductor to the LED rather than be directly obtained from the battery. If the inductor size L1 and peak current I_{PEAK} can be calculated such that the current just reaches zero in 1.7µs, then the power in the LED will not be too dependent on battery volts, since the average current in the LED will always be approximately I_{PEAK}/2.

As the battery voltage increases, the T_{ON} necessary to reach I_{PEAK} will decrease, but the LED power will be substantially constant and it will just draw a battery current ramping from zero to I_{PEAK} during T_{ON}. At higher battery voltages, T_{ON} will have a lower proportional of the total cycle time, so that the average battery current at higher battery voltage will be less, such that power (and efficiency) is conserved.

The forward voltage which is across the Schottky diode detracts from the efficiency. For example, assuming V_F of the LED is 6V and V_F of the Schottky is 0.3V, the efficiency loss of energy which is transferred from the inductor is 5%, i.e. the ratio of the Schottky forward drop to the LED forward drop. The Schottky is not in circuit during the T_{ON} period and therefore does not cause a loss, so the overall percentage loss will depend on the ratio of the T_{ON} and T_{OFF} periods. For low battery voltages where T_{ON} is a large proportion of the cycle, the Schottky loss will not be significant. The Schottky loss will also be less significant at higher LED voltages (more LED's in series) as Schottky drop becomes a lower percentage of the total voltage.

AN47

Getting more out of the ZXLD1350 - dimming techniques

Ray Liu, Systems Engineer, Zetex Semiconductors

Introduction

The ZXLD1350 has a versatile adjust pin that can be used in many ways to adjust the brightness of the LED by controlling the current in the LED. This application note deals with some the ways in which dimming the LED can be achieved and discusses the merits of the techniques. These dimming methods discussed include PWM dimming both with a low and high frequency signals, DC voltage control and resistive dimming.

Low frequency dimming

Low frequency dimming is preferred for LED dimming since the LED instantaneous driving current is constant. The color temperature of the LED is preserved at all dimming levels. Another advantage of low frequency dimming is that the dimming level can down to 1%. Hence result in dimming range of 100:1.

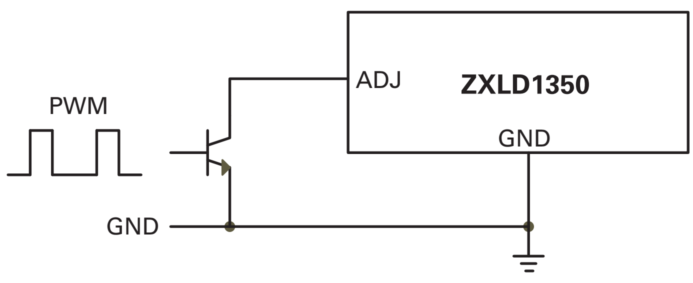
Choice of frequency

To avoid visible flicker the PWM signal must be greater than 100Hz. If you choose too high a frequency the internal low pass filter will start to integrate the PWM signal and produce a non linear response. Also the soft start function of the ADJ pin will cause a delay on the rising a falling edge of the PWM signal. This can give a non-linearity in the LED current which will have a greater affect as frequency increases.

An upper limit of 1kHz is suggested. The effect of audible noise in the inductor may need to be considered. This may happen in some inductors with loose windings and will be more noticeable at PWM frequencies of 1kHz than 100Hz.

If the PWM frequency is less than approximately 500Hz, the device will be gated 'on' and 'off' and the output will be discontinuous, with an average value of output current given by:

$$I_{OUT} \approx \frac{0.1\,D_{PWM}}{R_S} \quad \text{[for } 0<D_{WPM}<1\text{]}$$

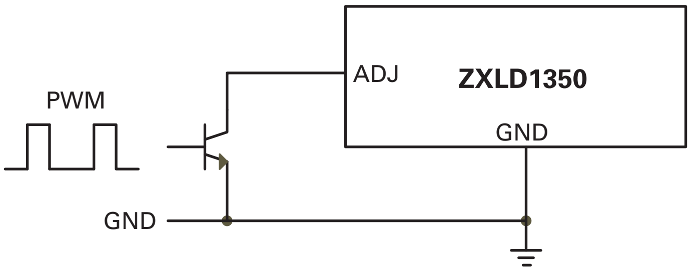


High frequency dimming

High frequency dimming is preferred if system required low radiated emission and in/output ripple. But dimming range is reduced to 5:1. The ZXLD1350 has an internal low pass filter which integrates the high frequency PWM signal to produce a DC dimming control.

If the PWM frequency is higher than approximately 10kHz and the duty cycle above the specified minimum value, the device will remain active and the output will be continuous, with a nominal output current given by:

$$I_{OUT} \approx \frac{0.1\,D_{PWM}}{R_S} \quad [\text{for } 0.16 < D_{PWM} < 1]$$



Input buffer transistor

For PWM dimming an input bipolar transistor with open collector output is recommended. This will ensure the 200mV input shutdown threshold is achieved.

It is possible to PWM directly without a buffer transistor. This must be done with caution. Doing this will overdrive the internal 1.25V reference. If a 2.5V input level is used at 100% PWM (DC) the output current into the LED will be 2X the normal current which may destroy the ZXLD1350. Overdriving with a 5V logic signal is very likely to damage the device as it exceeds the ADJ pin voltage rating.

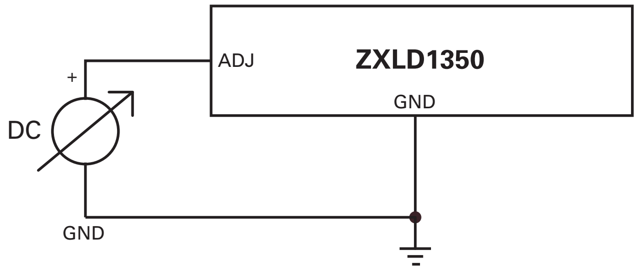
Soft start and decoupling capacitors

Any extra capacitor on the ADJ pin will affect the leading and falling edge of the PWM signal. Take this into account as the rise time will be increased by approximately 0.5ms/nF.

Compare this with a 100Hz PWM. 50% duty cycle T_{on} and T_{off} are 5ms at 1% duty cycle T_{on} is 0.1ms. 1nF on the ADJ pin will cause 0.5ms rise time which result in an error and limitation in dimming at low duty cycles.

DC voltage dimming

The ADJ pin can be overdriven by an external DC voltage (V_{ADJ}), as shown, in order to override the internal voltage reference and adjust the output current to a value above or below the nominal value.



The nominal output current is then given by:

$$I_{OUT} \approx \frac{0.08 \times V_{ADJ}}{R_S} \quad \text{[for } 0.3 < V_{ADJ} < 2.5\text{V]}$$

Figure 1 shown the relationship of LED current against V_{ADJ} with V_{ADJMAX} =1.25V (V_{IN} = 12V).

Note that 100% brightness setting corresponds to V_{ADJ} = V_{REF} = 1.25V with R_S = 300mΩ. The minimum dimming ratio is governed by the V_{ADJON} which is 250mV typically. In this case, the minimum dimmable current is 20% of full LED current. This gives dimming ratio of 1:5.

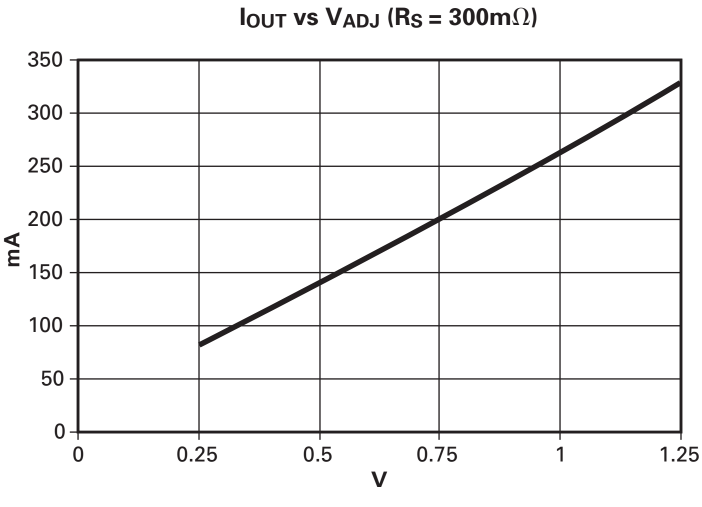


Figure 1 Typical output current versus ADJ voltage with R_S = 300mΩ

Switching frequency is another factor to consider for DC voltage dimming. Figure2 shows the relationship of switching frequency current against V_{ADJ} with L=100µH. As V_{ADJ} decreases, switching frequency increases. Care had to be taken for choosing the right inductor to achieve the desirable operating frequency range with the aid of the ZXLD1350 calculator.

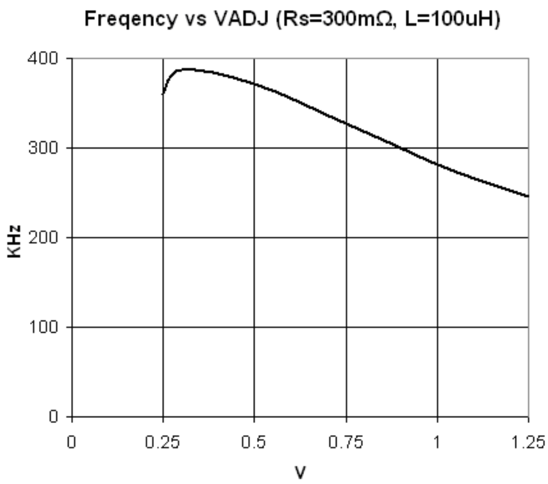


Figure 2 Typical switching frequency versus ADJ voltage with R_S = 300mΩ, L=100µH

In order to maximize the dimming ratio, we could increase the maximum value of V_{ADJ} to 2.5V. In this case, the minimum dimmable current is 10% of full LED current. This gives dimming ratio of 1:10. R_{SENSE} should then be increased by 2X R_S. This will slightly decrease the efficiency by 1 to 2%.

Figure 3 shows the relationship of LED current against V_{ADJ} with V_{ADJMAX} = 2.5V (V_{IN} = 12V).

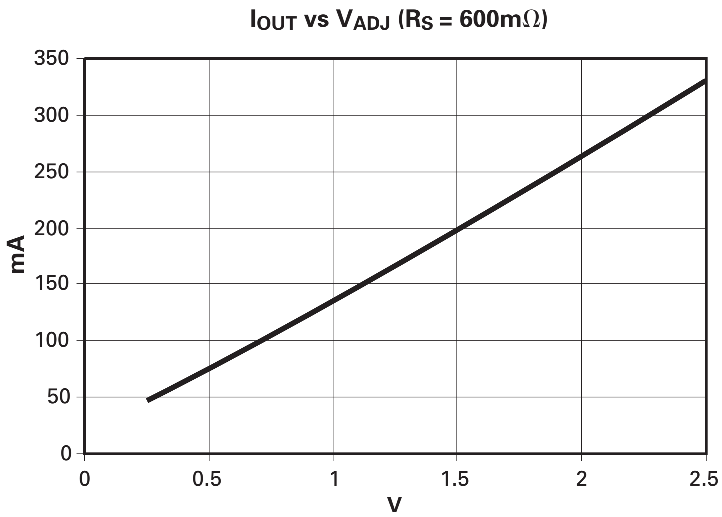


Figure 3 Typical output current versus ADJ voltage with R_S = 600mΩ

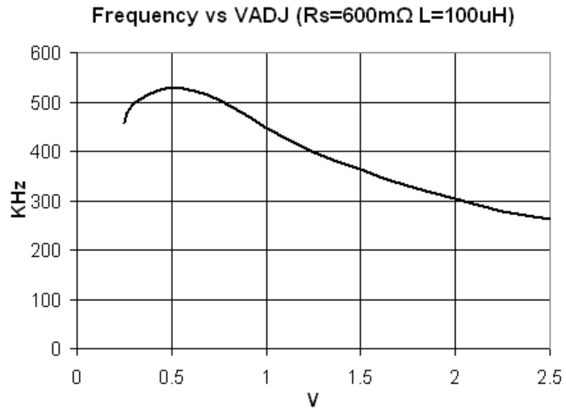


Figure 4 Typical switching frequency versus ADJ voltage with R_S = 600mΩ, L=100μH

The input impedance of the ADJ pin is 200kΩ ±20%. This may be the factor to consider if the DC dimming voltage is from a relatively high output resistance. Figure 5 shows a typical circuit that would provide 1.25V dimming voltage.

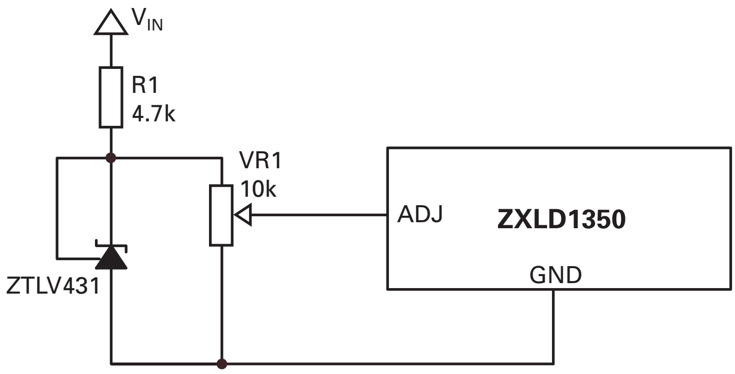


Figure 5 Typical circuit of DC voltage dimming

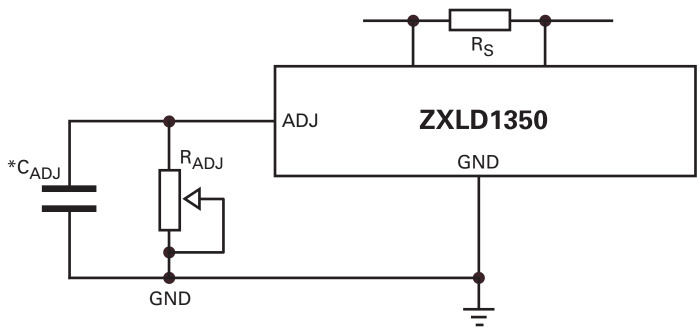
The ZTLV431 acts as a shunt regulator to generate an external 1.25V reference voltage. The reference voltage is applied to pot VR1 to provide dimming voltage of 0-1.25V.

Using an external regulator affects the accuracy of the current setting. If a 1% reference is used the LED current will be more accurate than using the internal reference.

Resistor dimming

By connecting a variable resistor between ADJ and GND, simple dimming can be achieved.

Capacitor C_{ADJ} is optional for better AC mains interference and HF noise rejection. Recommend value of C_{ADJ} is 0.22µF.



The current output can be determined using the equation:

$$I_{OUT} = \frac{(0.08/R_S) \times R_{ADJ}}{(R_{ADJ} + 200k)}$$

Note that continuous dimming is not possible with a resistor. At some point the shutdown threshold will be reached and the output current reduced to zero. This can occur below 300mV.

Note that a 1MΩ resistor will load the V_{REF} on the ADJ pin. The V_{REF} will now be divided down by the nominal 200k V_{REF} resistance and the 1M R_{ADJ}. The nominal voltage will now be approximately 1V. R_S will need to be adjusted to set the maximum current.

The +/20% tolerance of the input resistance should also be understood. See table below:

R_{ADJ} kΩ	Rint nom. kΩ	Rint min. kΩ	Rint max. kΩ	V_{ADJ} nominal	% error from nominal due to Rint min.	% error from nominal due to Rint max.
1000	200	160	240	1.041	3.4%	-3.3%
500	200	160	240	0.892	6.1%	-5.7%
200	200	160	240	0.625	11.1%	-10.0%
100	200	160	240	0.416	15.4%	-13.3%

Table 1

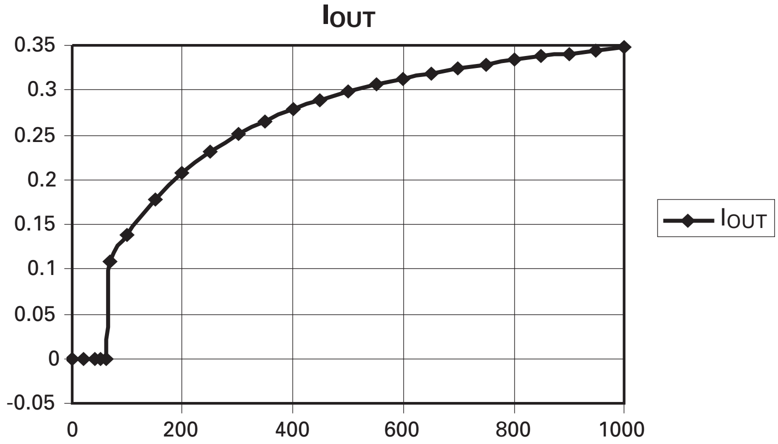


Figure 6 Typical output current against pot resistance

If linear pot is used, the output current change is not linear against shaft rotation.

In order to make the output current more linear, a log type pot is used.

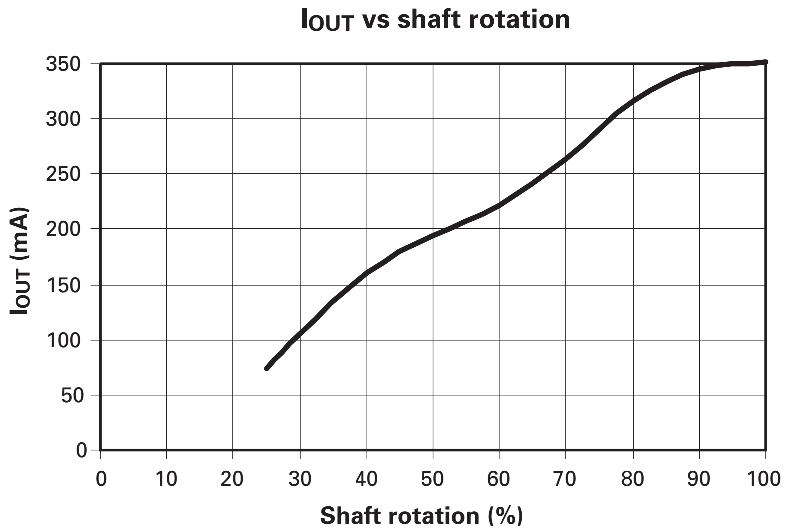


Figure 7 Output current against shaft rotation of log type pot

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![ZETEX SEMICONDUCTORS]

AN48
Getting more out of the ZXLD1350 - high output current

Ray Liu, Systems Engineer, Zetex Semiconductors

Introduction

The ZXLD1350 is a continuous mode inductive step-down converter, designed for driving single or multiple series connected LEDs efficiently from a voltage source higher than the LED voltage. The device operates from an input supply between 7V and 30V and provides an externally adjustable output current of up to 350mA. In order to obtain higher output current to drive LEDs with higher power, a high current externally connected output stage is required.

700mA driver for multiple 3W LEDs in series

This driver is designed to drive up to six 3W LEDs in series which could deliver total output power of 15W with an overall efficiency of around 90%.

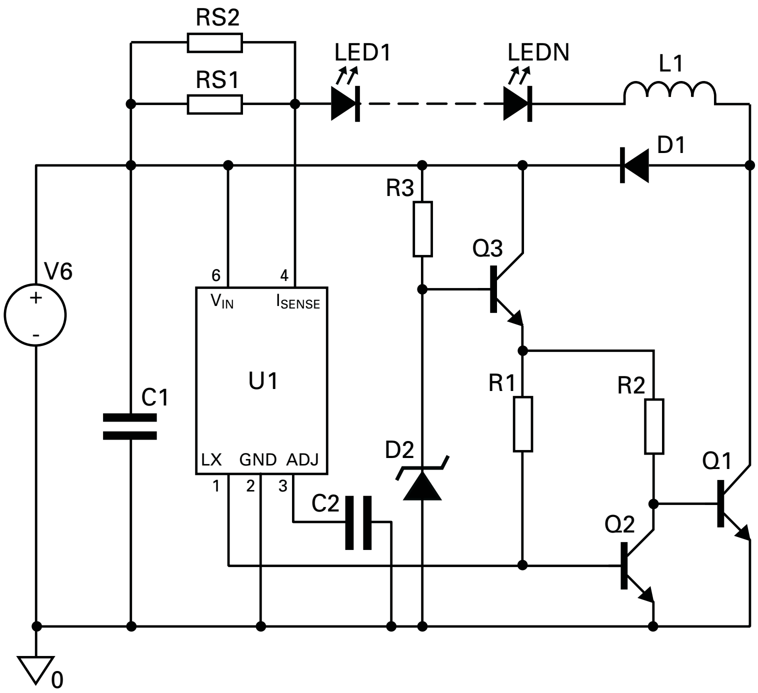


Figure 1 Schematic of 700mA driver

Part list

Table 1

Part ref.	Part no.	Remark
U1	ZXLD1350	
Q1	FCX619	
Q2	FMMT619	
Q3	FMMT619	
D1	ZLLS1000	
D	25.6V Zener diode	
L1	68µH 1A	
RS1	150mΩ	
RS2	2.2Ω	
R1	2.2KΩ	
R2	470Ω	
R3	15KΩ	
C1	3.3µF 50V	X5/7R or other low ESR cap
C2	0.1µF	Optional

Circuit description

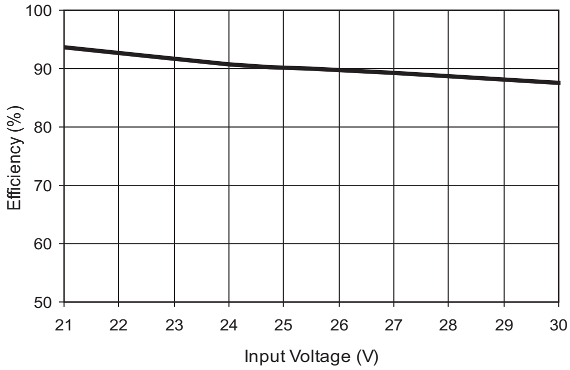
The output driver consists of two NPN transistors (Q1 and Q2). Transistor Q2 acts as a small signal inverter which inverts the original LX switch signal. The collector of Q2 is connected to the base of transistor Q1 which acts as the power output switch.

Transistor Q3 and Zener diode D2 form a simple regulator to supply a constant voltage to the driver stage. The voltage at emitter of Q3 is around 5V. This helps to provide a stable driving current to both Q1 and Q2. The driving currents are around 2mA and 9mA respectively.

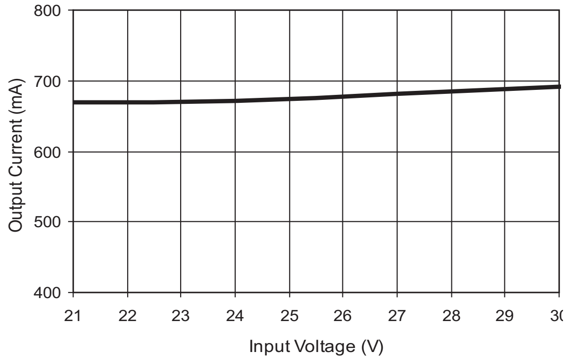
Total propagation delay is less than 200ns against the LX pin. Both the rise time and the fall time of the output switch are less than 70ns when input supply voltage is 30V.

Typical performance graphs

5 LEDs in series with total V_F = 17.9V

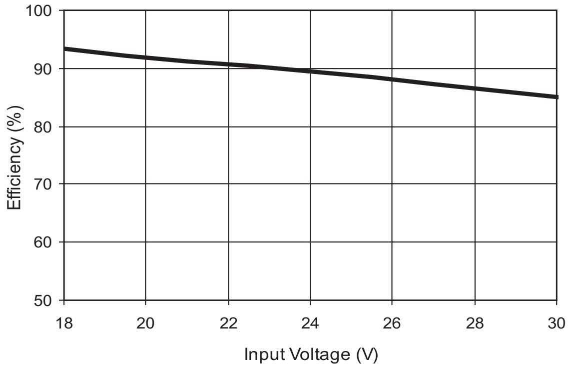


Efficiency vs Input Voltage (5 LEDs)

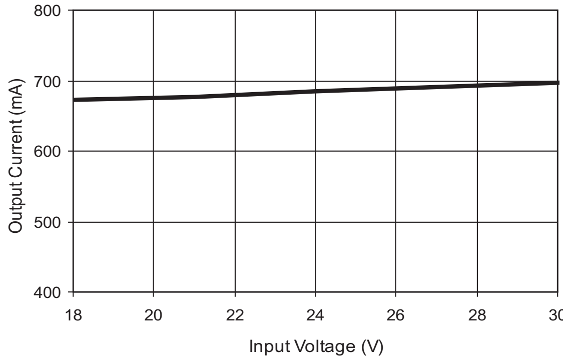


Output Current vs Input Voltage (5 LEDs)

4 LEDs in series with total V_F = 14.9V

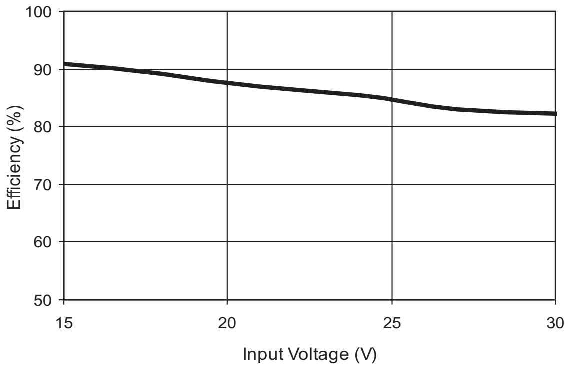


Efficiency vs Input Voltage (4 LEDs)

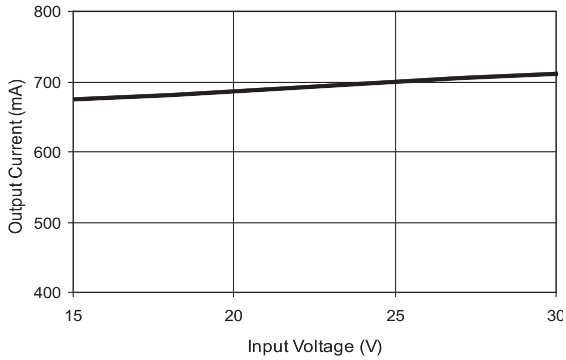


Output Current vs Input Voltage (4 LEDs)

3 LEDs in series with total V_F = 11.1V



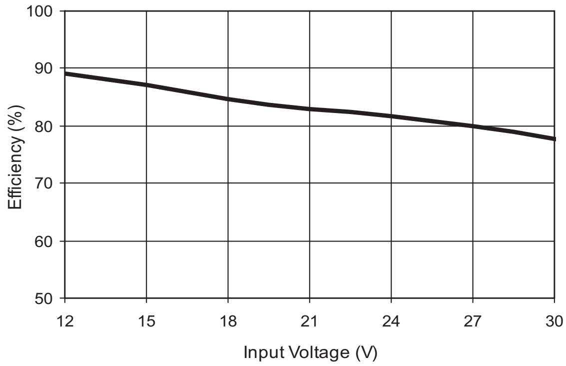
Efficiency vs Input Voltage (3 LEDs)



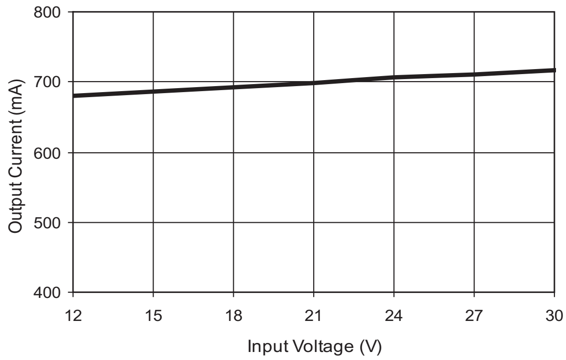
Output Current vs Input Voltage (3 LEDs)

Typical performance graphs (cont.)

2 LEDs in series with total V_F = 7.7V

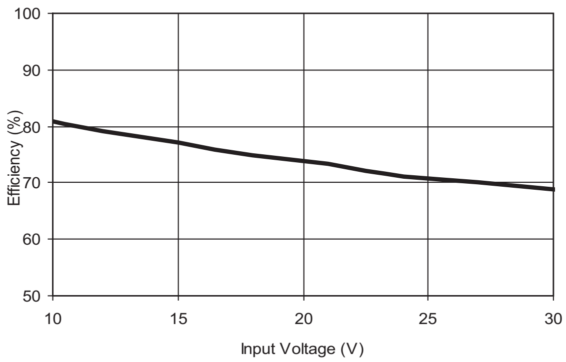


Efficiency vs Input Voltage (2 LEDs)

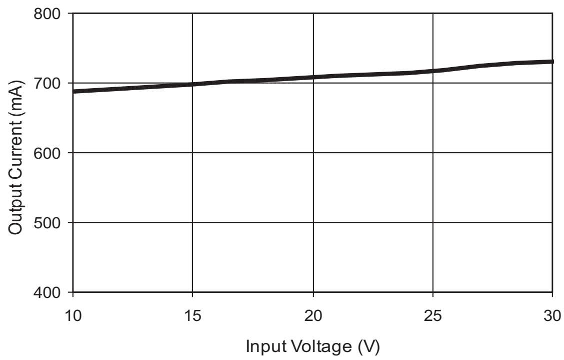


Output Current vs Input Voltage (2 LEDs)

1 LED in series with V_F = 3.8V



Efficiency vs Input Voltage (1 LED)



Output Current vs Input Voltage (1 LED)

A driver for supply voltage up to 16V

This driver is a simplified version to the 700mA driver described above. The driver is designed to drive up to 3 Luxeon® K2 LEDs in series which could deliver a total output power of 10W with a maximum input supply voltage of 16V.

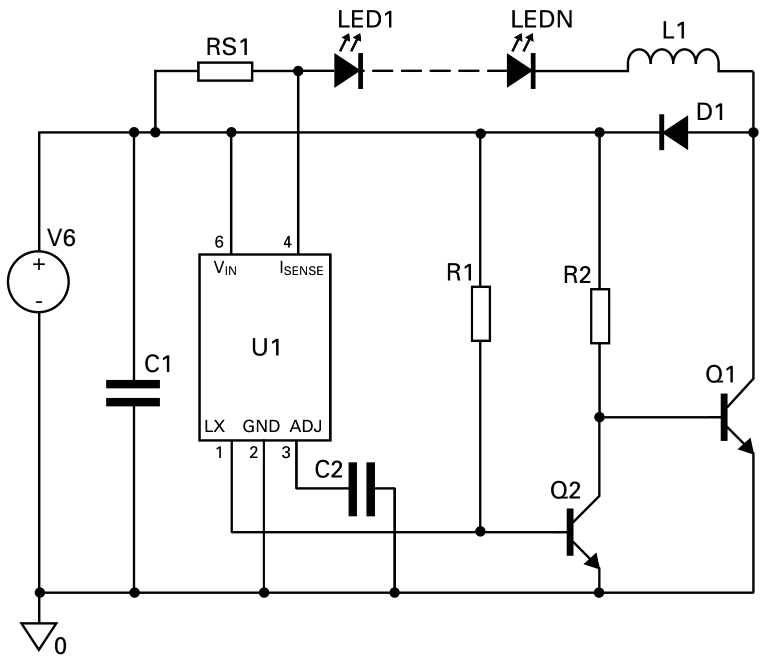


Figure 2 Schematic of 1A driver

Part List

Table 2

Part ref.	**Part no.**	**Remark**
U1	ZXLD1350	
Q1	ZXTN25020DFH	
Q2	ZXTN25020DFH	
D1	ZLLS2000	
L1	47µH 1.5A	
RS	100mΩ	
R1	4.7KΩ	
R2	1.5KΩ	
C1	4.7µF 25V	X5/7R or other low ESR cap
C2	0.1µF	Optional

Circuit description

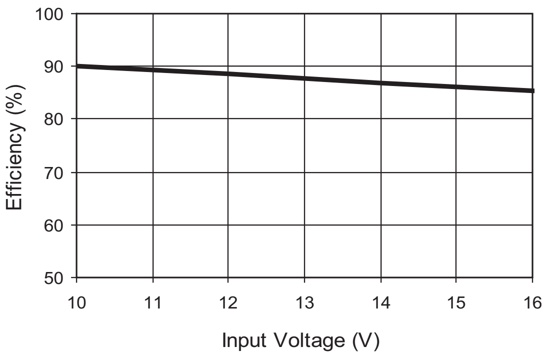
This circuit is similar to the 700mA driver described above. The output driver consists of two NPN transistors (Q1 and Q2). Transistor Q2 acts as a small signal inverter which inverts the original LX switch signal. The collector of Q2 is connected to the base of transistor Q1 which act as the power output switch.

Unlike the 700mA driver, the driving current to both Q1 and Q2 varies with the input supply voltage. Hence, the maximum input supply voltage is limited to 16V. The driving current to Q1 is between 5mA and 10mA with input supply voltage between 8V and 16V. Lowering the maximum supply voltage to 16V enables us to use a lower voltage BJT with better switching performance.

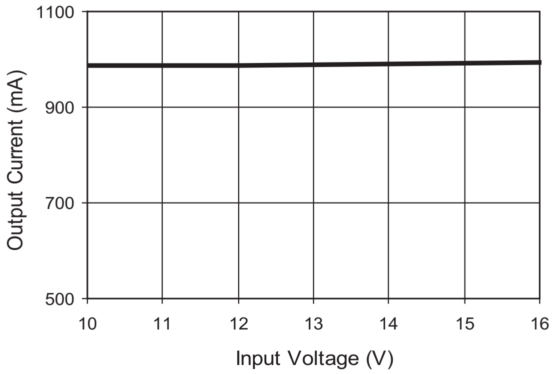
Total propagation delay is less than 200ns against the LX pin. Both the rise time and the fall time of the output switch are less than 60ns when input supply voltage is 16V.

Typical performance graphs

2 LEDs in series with total V_F = 7.1V

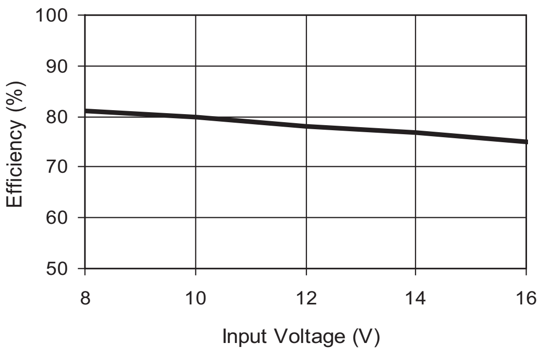


Efficiency vs Input Voltage (2 LEDs)

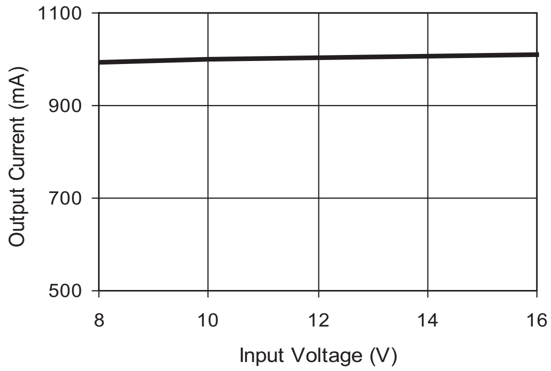


Output Current vs Input Voltage (2 LEDs)

1 LED in series with total V_F = 3.5V



Efficiency vs Input Voltage (1 LED)



Output Current vs Input Voltage (1 LED)

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AN50
Feed forward compensation for ZXSC300 LED driver

Yong Ang, Application Engineer, Zetex Semiconductors

Input voltage feed forward compensation for ZXSC300 to improve control of the LED current

Introduction

The ZXSC300 LED drivers do not directly control the LED current. As a consequence the LED current is dependent of the input voltage. This application note describes a way of reducing the supply voltage dependency by a method of supply voltage feed forward compensation. The method can also be used to provide temperature compensation of the LED.

The ZXSC300 works on the PFM control scheme where the LED current is simply regulated by controlling the peak current through transistor Q1. The internal voltage threshold of current sense pin is around 19mV and transistor Q1 is switched off when its current reaches the preset threshold, thereby necessitating fewer external components required. However, this threshold value is invariant to the supply voltage level. In the event where input voltage increases, peak Q1 current will stay the same and current delivered to the LED creeps up which could potentially damage the LED if it exceeds the maximum rated current of the device.

The circuit diagram in Figure 1 shows how to apply input voltage and thermal correction to a typical LED. A simple design guide for a single LED driver has also been put forward. The equations can generate a design capable of sourcing up to 200mA LED current, when used with the Zetex high current gain NPN transistor-ZXTN25012EFH.

Input voltage feed forward compensation

Normally, I_{PK} is set by the output current threshold voltage V_{ISENSE} divided by R_{SENSE}. As the input voltage increases, the inductor ripple current level ΔI decreases because the transistor off time, T_{OFF} is fixed by the ZXSC300

$$\Delta I = (V_{OUT} - V_{IN}) \bullet T_{OFF} \div L$$

L discharges at a flatter slope to a higher minimum choke current $I_{MIN} = I_{PK} - \Delta I$, before transistor Q1 is turned on again.

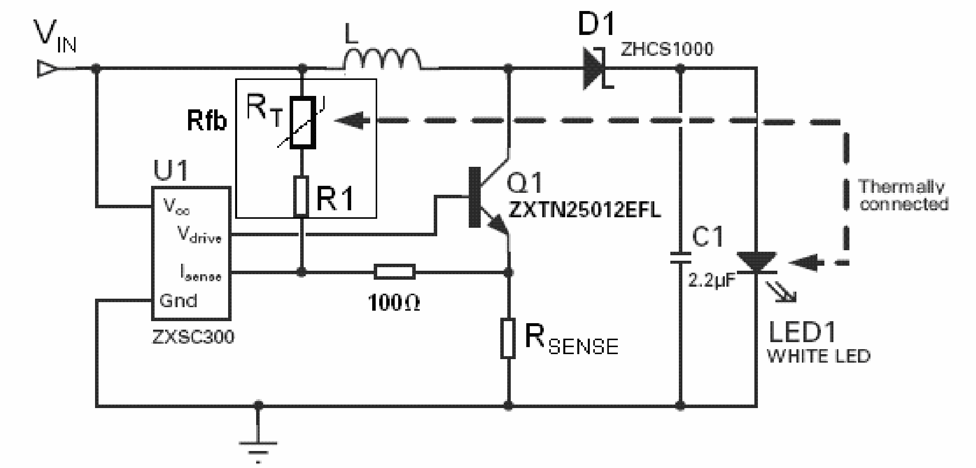

Figure 1 Circuit diagram of ZXSC300 with feed forward and thermal compensation

Consequently, the average current I_{AV} flowing through L increases and a shorter transistor on time, TON is required to charge boost inductor to the preset threshold current level I_{PK}

$$T_{ON} = \Delta I \bullet L \div V_{IN}$$

By making the aforementioned assumptions for turn-on period and average coil current, the output power delivered to the LED is now determined from

$$P_{OUT} = V_{LED} \bullet I_{AV} \bullet T_{OFF} \div (T_{ON} + T_{OFF})$$

Therefore, a higher power and LED current is delivered to the LED at high V_{IN} for a fixed R_{SENSE} and this elevated current could potentially damage the LED if it exceeds the maximum rated current of the device.

Ignoring the effect of thermistor R_T for the moment, a 100Ω resistor R_{OFF} can be inserted in series with R_{SENSE} and feed forward resistor Rfb (see Figure 1) to inject a slight voltage offset across resistor R_{SENSE}. This enables a lower Q1's current to build up the required V_{ISENSE} to turn the driver off, which regulates the LED current. The Rfb value has to be sufficiently big to lower dissipation and to prevent circuit from stalling. The circuit could stall at high input voltage if Rfb drops 19mV or more across 100Ω resistor forcing the driver off all the time.

It must be noted that I_{SENSE} pin threshold on ZXSC300 has a positive temperature coefficient of 0.4%/°C. If a circuit nominal operating temperature is higher than 65°C, it could give approximately 20% increase in average LED current from that in 25°C ambient. When a feed forward network is used, this injects an offset voltage to the threshold pin. For instance, if an offset voltage of 9.5mV is used, the effective V_{ISENSE} temperature coefficient becomes double. Therefore, it is essential that thermal compensation is used with a feed forward approach.

Feed forward components calculation

For initial estimation, the associated $I_{AV(VMAX)}$ that delivers the required LED current can be determined from

$$I_{AV(VMAX)} = P_{OUT} \div (F \bullet T_{OFF} \bullet V_{OUT})$$

Where the transistor switching frequency F is given by

$$F = V_{IN(MAX)} \div V_{OUT} \div T_{OFF}$$

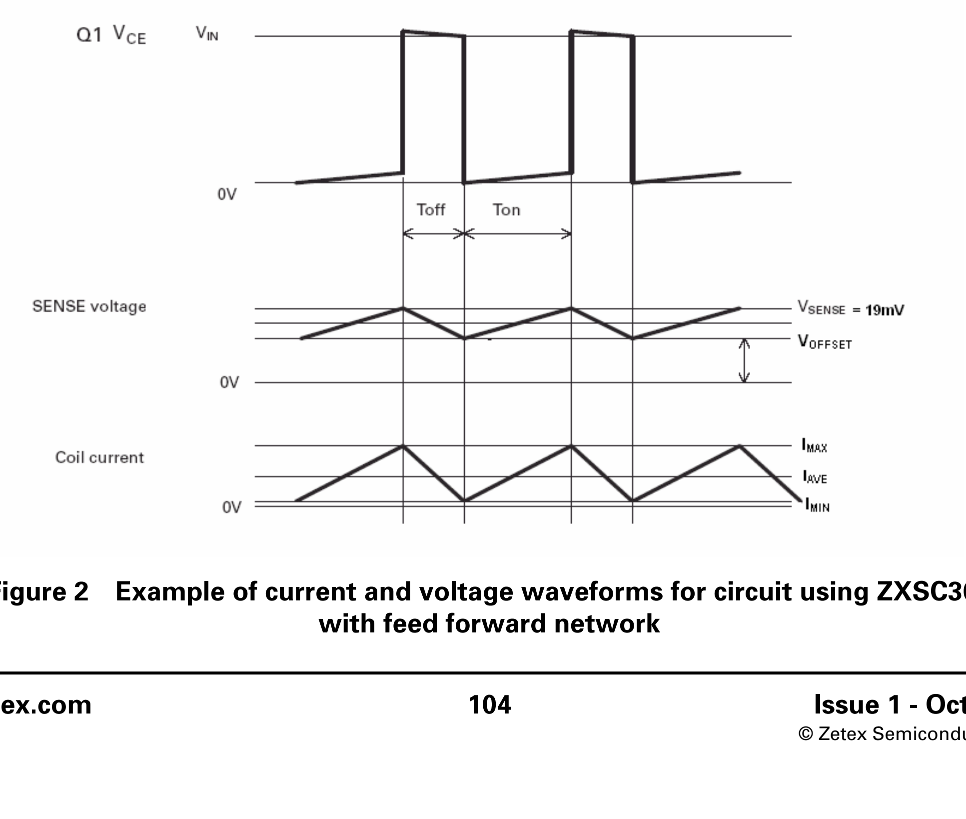

Figure 2 Example of current and voltage waveforms for circuit using ZXSC300 with feed forward network

$I_{AV(VMAX)}$ is used to establish the required DC current rating, I_{DC} for boost inductor L.

The minimum inductor current is given by,

$$I_{MIN(VMAX)} = I_{AVE} - 0.5 \bullet (V_{OUT} - V_{IN(MAX)}) \bullet T_{OFF} / L$$

A high L value is recommended to minimize errors due to propagation delays at high input voltage, which results in increased ripple and lower efficiency.

And the maximum inductor current which relates to the Q1 peak current is

$$I_{PK(VMAX)} = 2 \bullet I_{AVE} - I_{MIN(VMAX)}$$

In practice, a higher $I_{PK(VMAX)}$ value can be used to account for the V_{CE} saturation and switching edge loss in the transistor.

The value of feed forward resistor Rfb is selected to give $I_{PK(VMIN)}$ at worse case input voltage and $I_{PK(VMAX)}$ at maximum input voltage. The internal V_{ISENSE} threshold on the ZXSC300 is typically 19mV with ±25% tolerance at 25°C. R_{SENSE} has to drop less voltage than that demanded by V_{ISENSE} as Rfb will make a contribution to satisfy the threshold, which lowers I_{PK} value with increasing input. Allowing for the positive temperature coefficient on I_{SENSE} pin, effective threshold voltage level at operating temperature T_{AMB} is;

$$V_{ISENSE}@T_{AMB} = 19mV \pm 25\% \bullet 0.4\%/°C \bullet (T_{AMB} - 25°C).$$

At low supply voltage $V_{IN(MIN)}$

$$V_{ISENSE}@T_{AMB} = I_{PK(VMIN)} \bullet R_{SENSE} + V_{IN(MIN)} \bullet 100\Omega \div (Rfb + 100\Omega)$$

Whilst at $V_{IN(MAX)}$,

$$V_{ISENSE}@T_{AMB} = I_{PK(VMAX)} \bullet R_{SENSE} + V_{IN(MAX)} \bullet 100\Omega \div (Rfb + 100\Omega)$$

Solving the above simultaneous equations gives the required R_{SENSE} and Rfb resistor values. These design equations are also available as a spreadsheet calculator from Zetex website at

www.zetex.com/zxsc300feedforward

Figure 3 shows the measured LED current against variation in the input voltage with feed forward compensation. For comparison purpose, the same measurement is repeated with feed forward network removed, in which case the LED current at low supply is 3 times lower than that at nominal input voltage level.

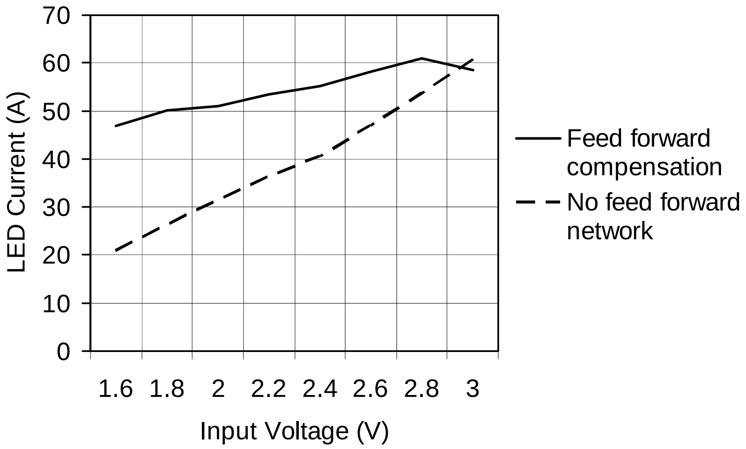

Figure 3 LED current discrepancy for ZXSC300 with feed forward compensation

The improvement in LED current regulation through feed forward compensation is self-evident. Although some discrepancy in LED current persists at low supply, this is predominantly due to the dependency of internal V_{ISENSE} threshold level on the input voltage level.

To incorporate thermal compensation into the design, Rfb can be made up from a series combination of normal resistor R1 and NTC R_T. During start-up condition, the printed circuit board's and LED's temperatures are low, hence R_T has high resistance. As circuit temperature rises to its design operating value, the effective feed forward resistance drops, increasing the offset voltage on I_{SENSE} pin, which in turn matches the elevated V_{ISENSE} value and hence regulates the actual output current fed to the LED.

For instance, the required effective feed forward resistor value (R1+ R_T) for 25°C ambient start-up can be determined from

$$Rfb = V_{IN(MAX)} \bullet 100\Omega \bullet (19mV \pm 25\% - I_{PK(VMAX)} \bullet R_{SENSE})$$

And the required normal resistor R1 is equivalent to Rfb - R_T.

For this design, three NTC values (3.3KΩ, 4.7KΩ and 6.8KΩ) are recommended. These resistors with MURATA 0603 or 0805 size NTC thermistors with beta-constant value of 3950K are chosen to give good current control response at both normal operating temperature and start-up conditions. The NTC works to reduce the peak transistor current, facilitating thermal feedback control to ensure that LED current and lumen maintenance expectation are achieved. Note that it is sometimes difficult to achieve perfect LED current matching between start-up and normal operating temperature. In extreme cases of large temperature gradients, the average LED current should be lower at start-up giving less lumen output, and then ramps up to the rated current once it reaches the normal operating temperature. Furthermore, the thermistor can be thermally coupled to the LED to provide response tracking and prevent overheating.

Conclusion

Two or three additional external components can be used to provide input voltage feed forward for ZXSC300. This serves to ensure that the LED current is closely regulated. The LED current regulation improves significantly when feed forward compensation is employed. The LED current at the worse case input voltage increases from 33% to 64% of the nominal LED current with a feed forward network. The remaining discrepancy is predominantly due to the dependency of the VISENSE threshold level on the input voltage level.

In applications where the circuit is designed to operate in elevated ambient temperature, a NTC thermistor can be incorporated to facilitate thermal feedback control and prevent over heating.