Lighting Handbook

This handbook is a convenient collection of design notes that have been developed to support lighting application requirements. These design notes demonstrate the power and flexibility of the Zetex range of lighting DC-DC converters, switches and diodes. Application fits can be found for a wide range of end equipment. From driving white LEDs for back lighting color LCD displays, to single cell LED flash lights.

The products used in these notes are:

- ZXSC300 Single/multi cell LED driver
- ZXSC310 Single/multi cell LED drive with shut down
- ZXSC310 With reverse polarity protection
- ZXSC300 / ZXSC310 A high power LED driver for low voltage halogen replacement
- ZXSC400 LED driver with shut down
- ZXLD1100, ZXLD1101 LED drive with integrated switch
- ZXLB1600 LCD/OLED bias generator
- FMMT617, FMMT618, FMMT619 Low saturation NPN switch
- ZHCS500, ZHCS1000, ZHCS2000 Low Vf Schottky diode

Individual data sheets for these devices can be found on the Zetex web site.
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

Contents

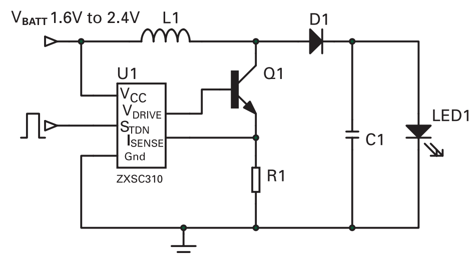
Design Note 61

ZXSC310 Solution for a 1W High Power White LED

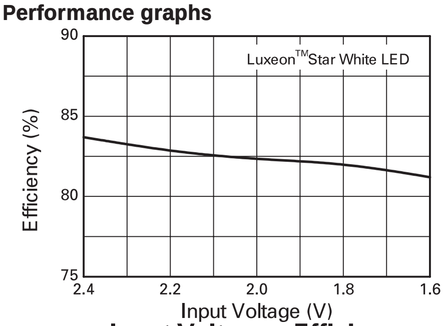
Aim

This design note shows the ZXSC310 driving a 1W LED. The LED has 180Cd light output from a forward current of 350mA. The solution is optimised to drive the 1W LED at 350mA DC current from a dual cell input.

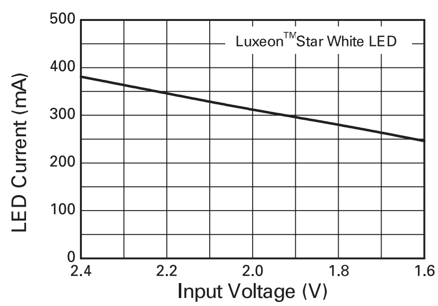
Circuit diagram



Performance graphs



Input Voltage v Efficiency



Input Voltage v LED Current

Bill of Materials

Reference	Part No.	Value	Manufacturer	Contact Details
U1	ZXSC310E5	LED driver	Zetex	www.zetex.com
Q1	FMMT617	3A, low $V_{CE(SAT)}$	Zetex	www.zetex.com
D1	ZHCS1000	2A, low V_F	Zetex	www.zetex.com
L1	DO3316P-223	22uH, 2A	Coilcraft	www.coilcraft.com
R1	Generic	22mΩ	Generic	
C1	Generic	2.2μF	Generic	
LED1	LXHL-NW98	White LED	Lumileds	www.lumileds.com

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ZETEX SEMICONDUCTORS

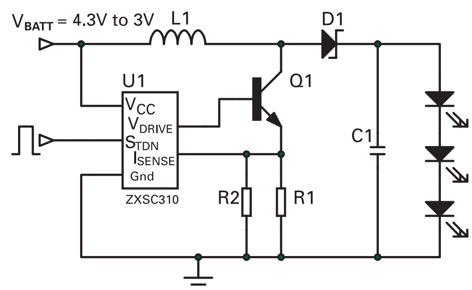
Design Note 62

ZXSC310 Solution to drive 3 LEDs connected in series

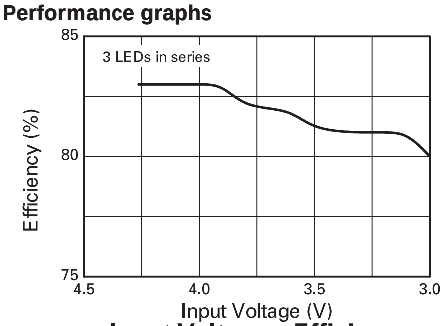
Aim

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.

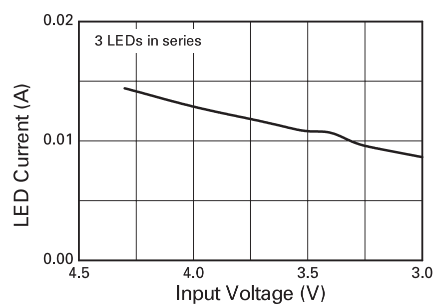
Circuit diagram



Performance graphs



Input Voltage v Efficiency



Input Voltage v LED Current

Bill of Materials

Reference	Part No.	Value	Manufacturer	Contact Details
U1	ZXSC310E5	N/A	Zetex	www.zetex.com
Q1	FMMT618	N/A	Zetex	www.zetex.com
D1	ZHCS1000	1A	Zetex	www.zetex.com
R1	Generic	510mΩ	Generic	
R2	Generic	510mΩ	Generic	
C1	Generic	2.2μF	Generic	
L1	DO1608P-103	10μH	Coilcraft	www.coilcraft.com
LED1-3	NSPW500BS	White LED	Nichia	www.nichia.com

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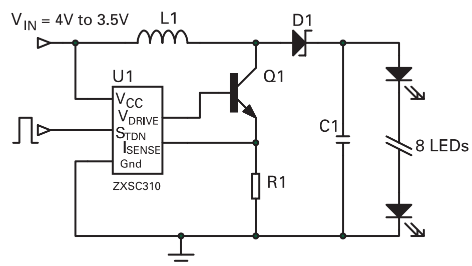
ZXSC310 Solution to drive 8 LEDs connected in series

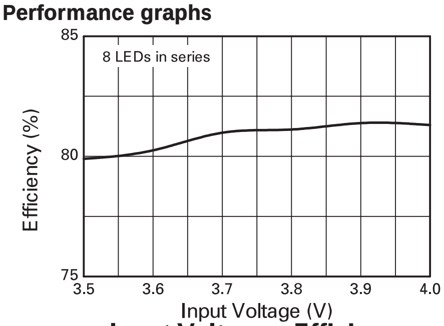
Aim

This solution is optimized for an input voltage range of 4V to 3.5V. The LED current is set to approximately at 25mA V_{IN} = 4V for 8 white LEDs connected in series.

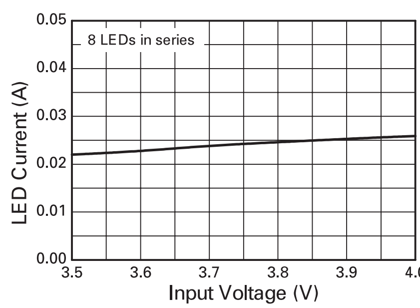
Circuit diagram



Performance graphs



Input Voltage v Efficiency



Input Voltage v LED Current

Bill of Materials

Reference	Part No.	Value	Manufacturer	Contact Details
U1	ZXSC310E5	N/A	Zetex	www.zetex.com
Q1	FMMT619	N/A	Zetex	www.zetex.com
D1	ZHCS1000	1A	Zetex	www.zetex.com
R1	Generic	47mΩ	Generic	
C1	Generic	2.2µF	Generic	
L1	DO1608P-683	68µH	Coilcraft	www.coilcraft.com
LED1-8	NSPW500BS	White LED	Nichia	www.nichia.com

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ZETEX SEMICONDUCTORS

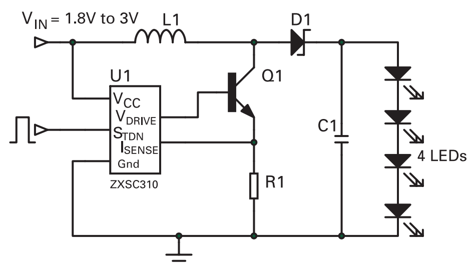
Design Note 64

ZXSC310 Solution Flashlight

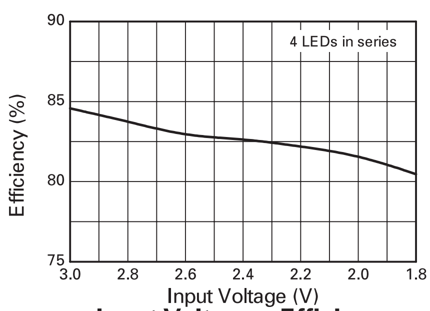
Aim

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

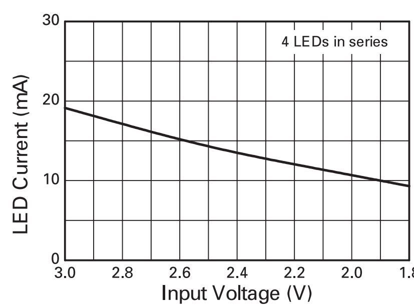
Circuit diagram



Performance graphs



Input Voltage v Efficiency



Input Voltage v LED Current

Bill of Materials

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	
C1	Generic	2.2μF	Generic	
LED1-4	Learn-4753A	White LED	LG Innotek	www.lginnotek.com

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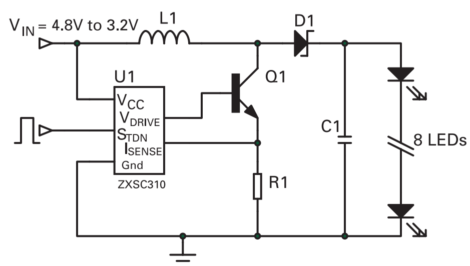
ZXSC310 Solution for Emergency Light

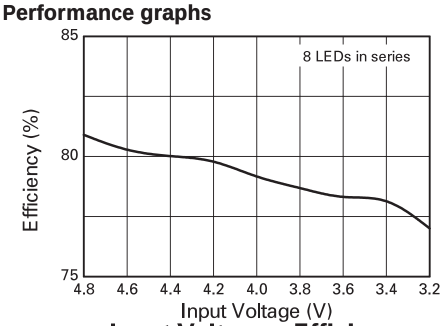
Aim

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

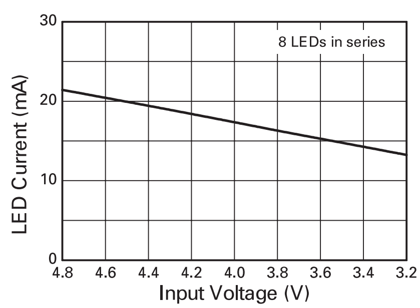
Circuit diagram



Performance graphs



Input Voltage v Efficiency



Input Voltage v LED Current

Bill of Materials

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	
C1	Generic	2.2µF	Generic	
LED1-8	NSPW500BS	White LED	Nichia	www.nichia.com

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Design Note 66

An OLED bias supply for a clamshell handset sub display

Introduction

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, one is lower power consumption and two 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.

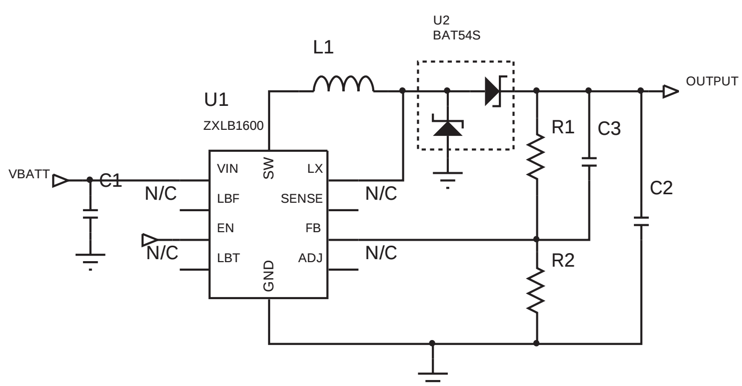


Figure 1.

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.)

Materials list

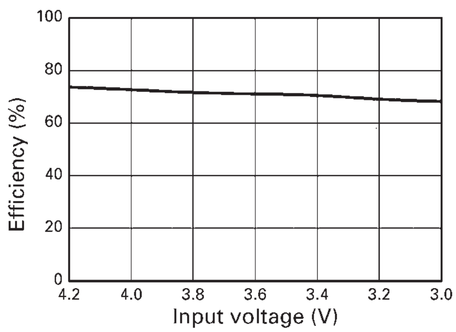
Ref.	Value	Part Number	Manufacturer	Comments
U1		ZXLB1600X10	Zetex	OLED Bias IC
U2		BAT54S	Zetex	Dual Schottky diode
L1	22μH	CMD4D11-220	Sumida	1mm height profile
R1	715kΩ	Generic	Generic	0603 Size
R2	82kΩ	Generic	Generic	0603 Size
C1	10μF/6V3	GRM Series	Murata	0805 size
C2(1)	10μF/16V	GRM Series	Murata	1206 size
C3	82pF/16V	Generic	Generic	0603 Size

NOTES:

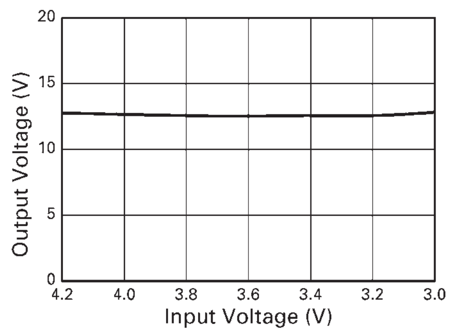
(1) For a lower profile, two 4.7μF 0805 capacitors can be used by connecting in parallel.

TYPICAL OPERATING CHARACTERISTICS

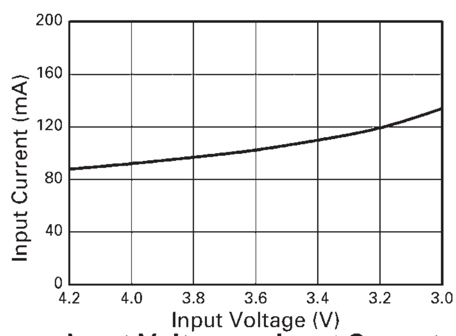
(For typical application circuit where V_{IN} = 3V, V_{OUT} = 12V, I_{OUT} = 20mA unless otherwise stated)



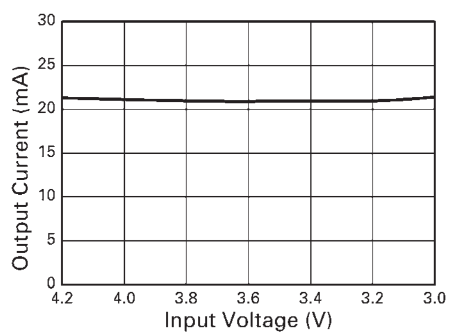
Input Voltage vs Efficiency



Input Voltage vs Output Voltage



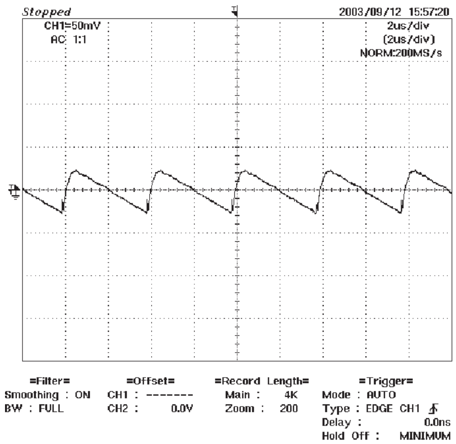
Input Voltage vs Input Current



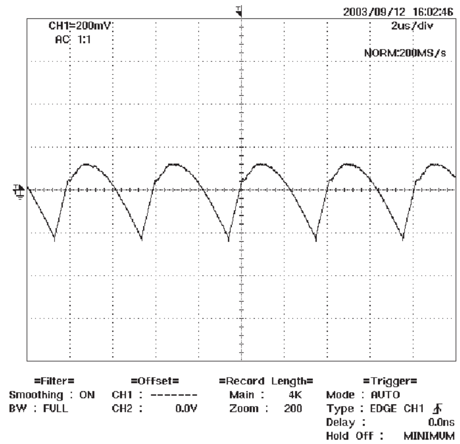
Input Voltage vs Output Current

TYPICAL OPERATING WAVEFORMS

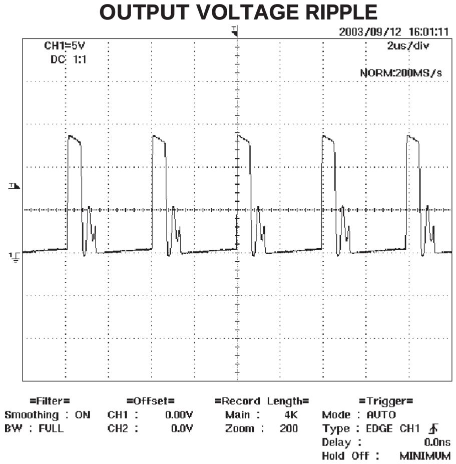
(For typical application circuit where V_{IN} = 3V, V_{OUT} = 12V, I_{OUT} = 20mA unless otherwise stated)



OUTPUT VOLTAGE RIPPLE



INPUT VOLTAGE RIPPLE



LX SWITCHING

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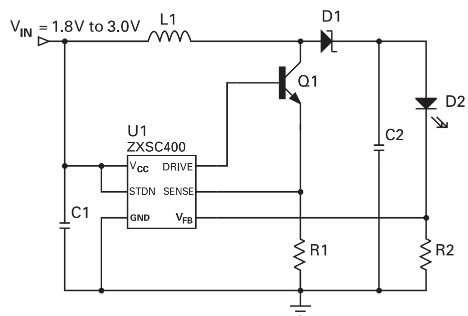
Design Note 67

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.



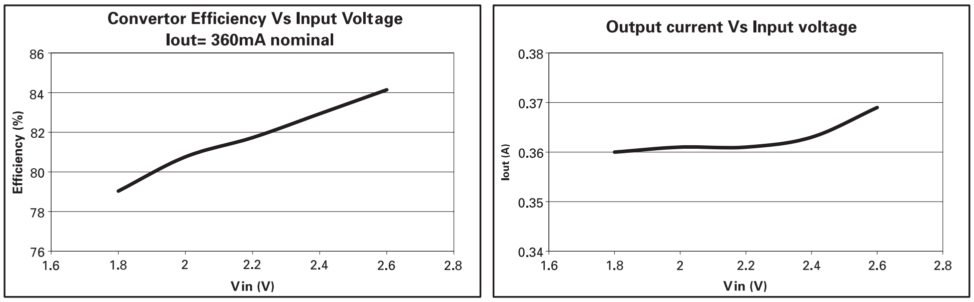
Bill of Materials

Reference	Part number	Value	Manufacture	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	
R2		0.82Ω	Generic	

NOTES:

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

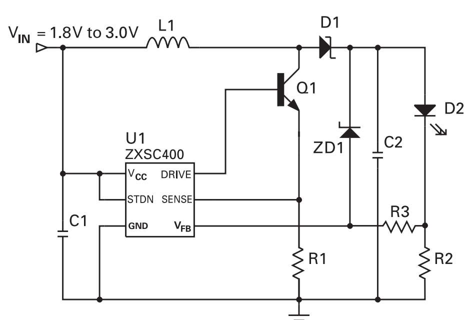
Figure 1 - Performance



Notes

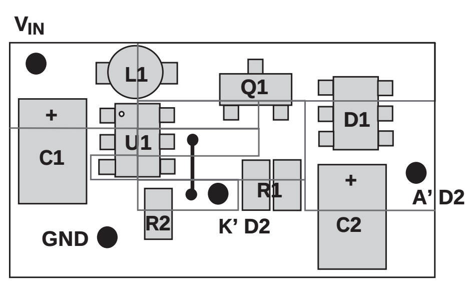
1. D1 can be exchanged with a SOT23 ZHCS1000 with a loss of 5% efficiency.
2. Inductor DCR (DC resistance) strongly influences efficiency, keep below 0.1Ω.
3. R1 is small and it is strongly advised to take track resistance into account. A proven method is to source a 1A current from the Sense pin to 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.

Figure 2 - Open circuit protection



Additional BOM
ZD1 - 5V6
R3 - 1KΩ

Figure 3 - Layout suggestion



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

NOTES:

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ZXSC310 High power torch reference design

Introduction

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.

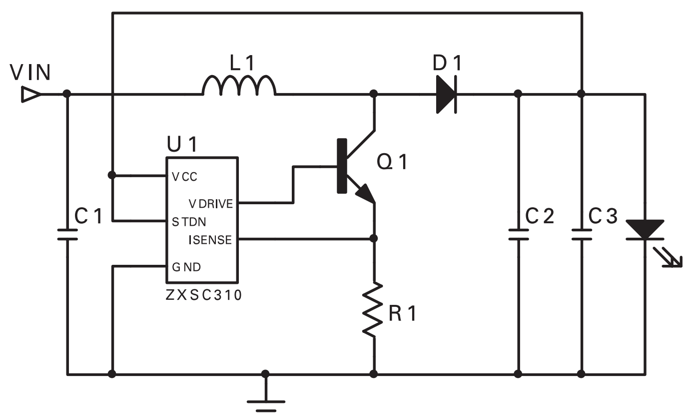


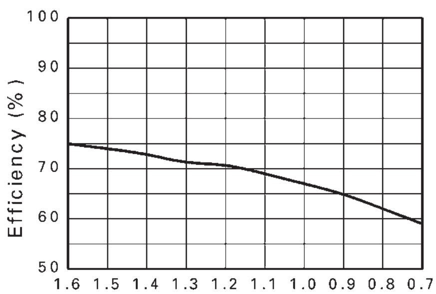
Figure 1

Materials list

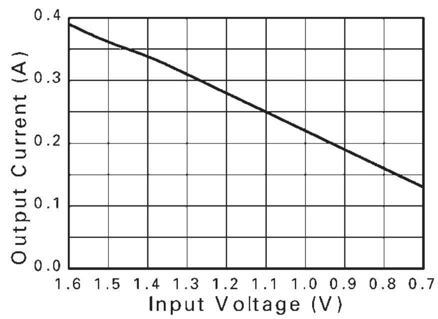
Ref	Value	Part Number	Manufacturer	Comments
U1		ZXSC310E5	Zetex	LED driver in SOT23-5
Q1		FMMT617	Zetex	Low sat NPN in SOT23
D1	2A	ZHCS2000	Zetex	2A Schottky in SOT23
L1	7.5µH	DO3316P-153x2	Coilcraft	I_{SAT} =3A
R1	19.5mΩ	Generic	Generic	0805 size
C1	1µF	Generic	Generic	
C2	220µF	Generic	Generic	
C3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

Typical operating characteristics

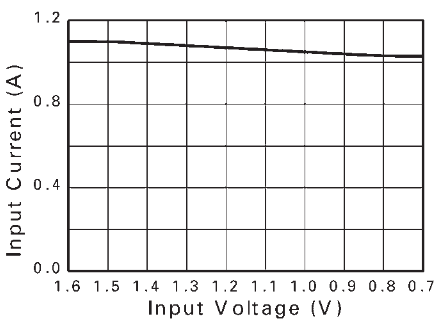
(For typical application circuit where T_A=25°C unless otherwise stated)



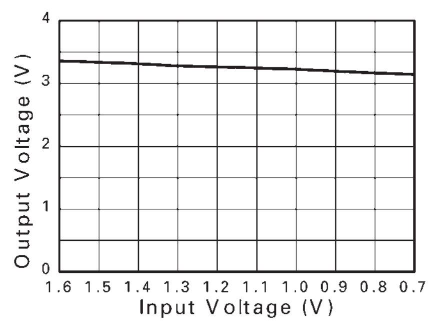
Input Voltage vs Efficiency



Input Voltage vs Output Current



Input Voltage vs Input Current



Input Voltage vs Output Voltage

Europe	Americas	Asia Pacific	Corporate Headquaters
Zetex GmbH	Zetex Inc	Zetex (Asia) Ltd	Zetex plc
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Design Note 69

ZXSC310 Garden light reference design

Introduction

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.

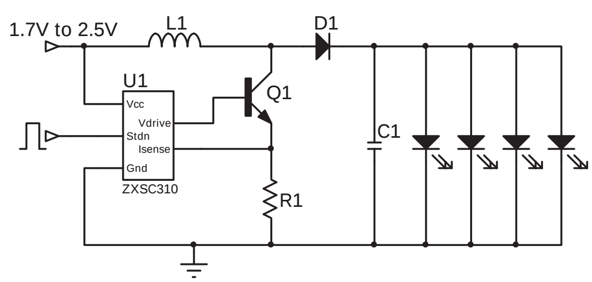


Figure 1

Materials list

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

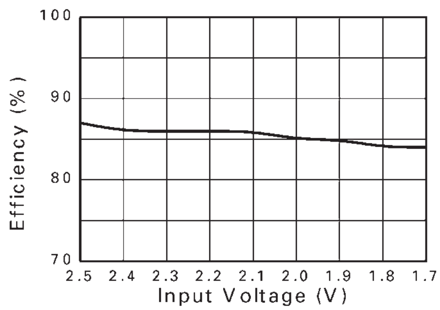
Total output current

The table opposite 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.

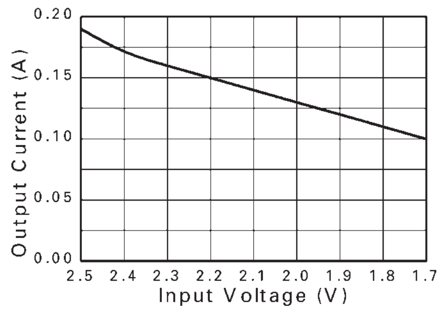
Total LED Current (mA)	4 LEDs	5 LEDs	6 LEDs
176	44	35	29
163	41	33	27
153	38	31	25
141	35	28	23
131	33	26	22
119	30	24	20
110	27	22	18
97	24	19	16
89	22	18	15
80	20	16	13
70	18	14	12
61	15	12	10

Typical operating characteristics

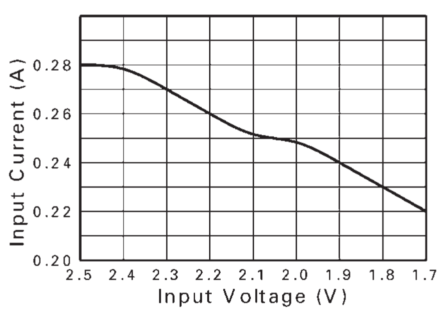
(For typical application circuit where TA=25°C unless otherwise stated)



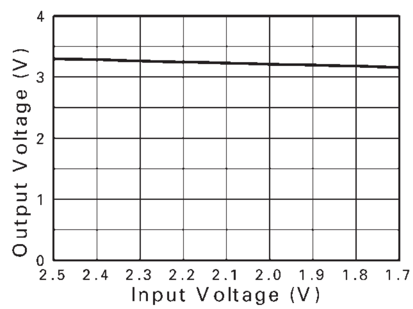
Input Voltage vs Efficiency



Input Voltage vs Output Current



Input Voltage vs Input Current



Input Voltage vs Output Voltage

Europe	**Americas**	**Asia Pacific**	**Corporate Headquaters**
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ZXSC400 Driving 2 serial high power LEDs

Introduction

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 497mA at 3.4V input.

A typical schematic diagram is shown in figure 1.

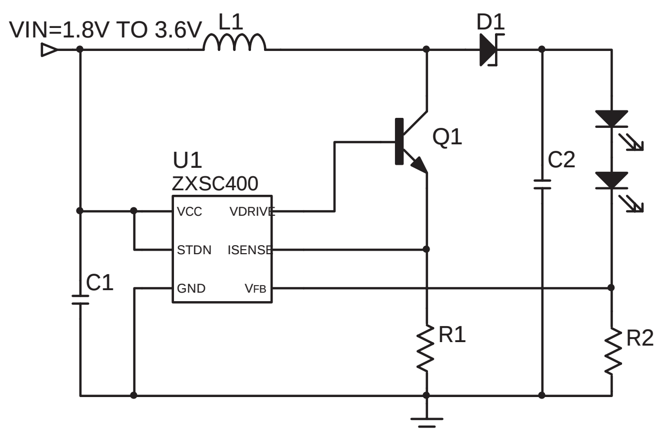


Figure 1

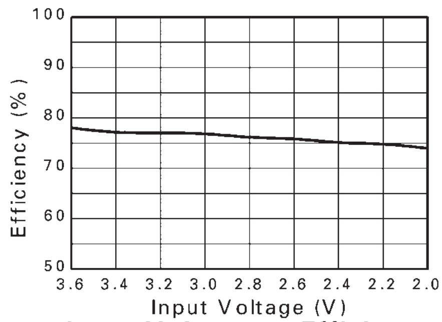
Materials list

Ref	Value	Part Number	Manufacturer	Comments
U1		ZXSC400E6	Zetex	LED driver in SOT23-6
Q1		FMMT617	Zetex	Low sat NPN in SOT23
D1	1A	ZHCS1000	Zetex	1A Schottky in SOT23
L1	22µH	Generic	Generic	I_{SAT}=3A
R1	16.5mΩ	Generic	Generic	0805 size
R2(1)	0Ω	Generic	Generic	0805 size
C1	100µF	Generic	Generic	
C2	100µF	Generic	Generic	

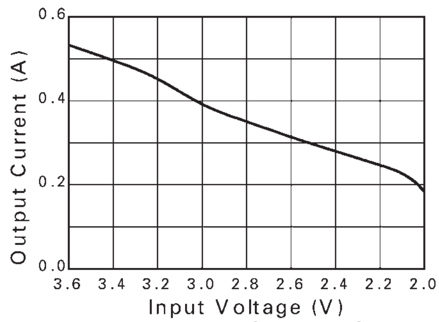
(1) R2 is set to zero. It shows the maximum output power characteristic of the LED driver. A regulated LED current below the maximum value can be set by: $I_{LED}=V_{FB}/R2$, where V_{FB}=0.3V.

Typical operating characteristics

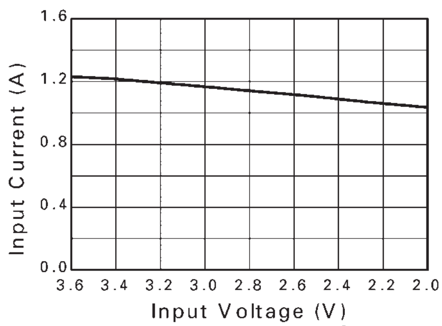
(For typical application circuit where TA=25°C unless otherwise stated)



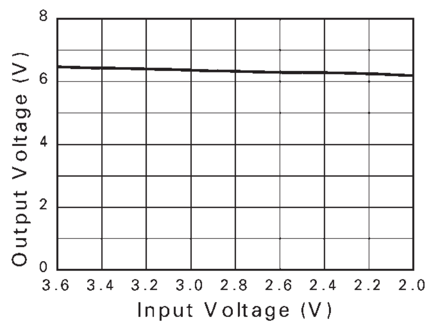
Input Voltage vs Efficiency



Input Voltage vs Output Current



Input Voltage vs Input Current



Input Voltage vs Output Voltage

Europe	Americas	Asia Pacific	Corporate Headquaters
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Design Note 71

ZXSC400 solution for Luxeon® V Star high powered LED

Introduction

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 790mA at 5V input.

A typical schematic diagram is shown in figure 1.

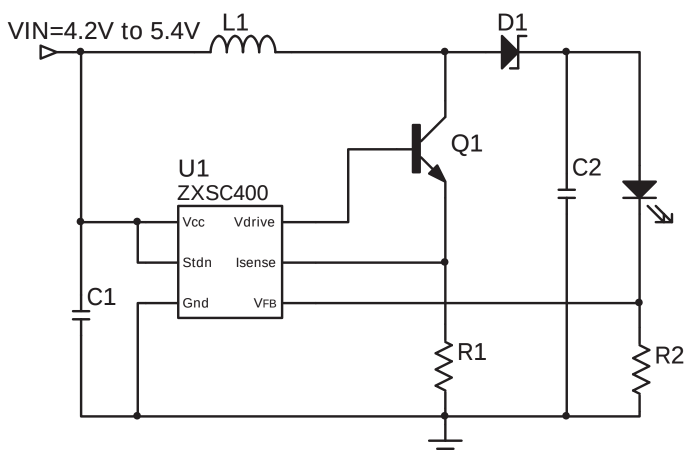


Figure 1

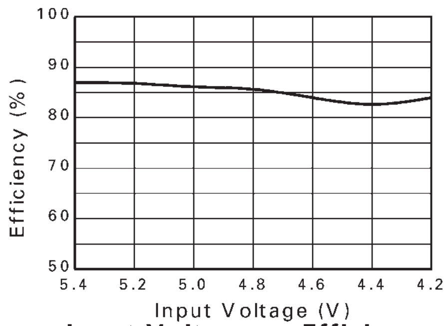
Materials list

Ref	Value	Part Number	Manufacturer	Comments
U1		ZXSC400E6	Zetex	LED driver in SOT23-6
Q1		FZT1049	Zetex	Low sat NPN in SOT23
D1	2A	ZHCS2000	Zetex	2A Schottky in SOT23
L1	22µH	Generic	Generic	I_{SAT}=3A
R1	22mΩ	Generic	Generic	0805 size
R2	350mΩ	Generic	Generic	0805 size
C1	220µF	Generic	Generic	
C2	450µF	Generic	Generic	

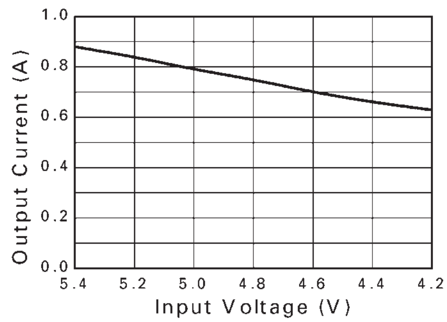
ZETEX SEMICONDUCTORS

Typical operating characteristics

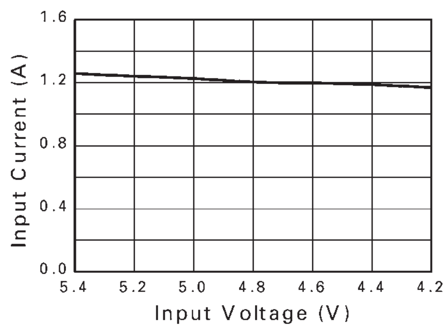
(For typical application circuit where T_A=25°C unless otherwise stated)



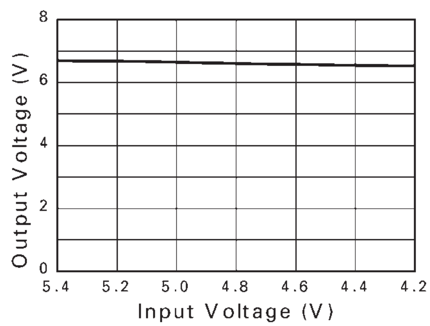
Input Voltage vs Efficiency



Input Voltage vs Output Current



Input Voltage vs Input Current



Input Voltage vs Output Voltage

Europe	**Americas**	**Asia Pacific**	**Corporate Headquaters**
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Design Note 72

ZXLD1101 Driving 8 Series LEDs

Introduction

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.

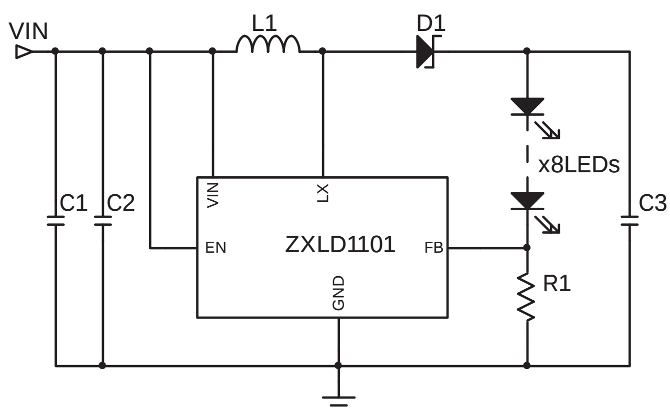


Figure 1

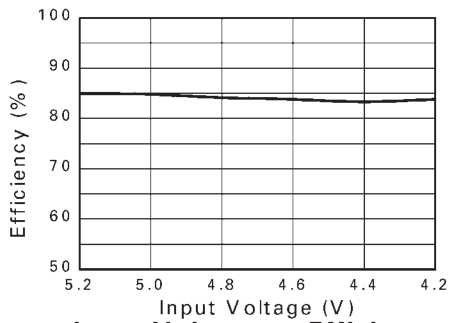
Materials list

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	

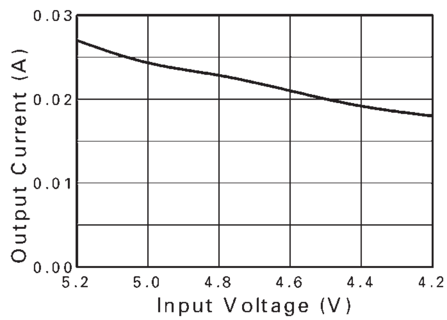
(1) R1 is set to zero. It shows the maximum output power characteristic of the LED driver. A regulated LED current below the maximum value can be set by: $I_{LED}=V_{FB}/R1$, where $V_{FB}=0.1V$.

Typical operating characteristics

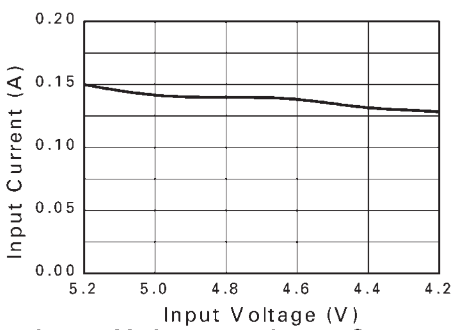
(For typical application circuit where T_A=25°C unless otherwise stated)



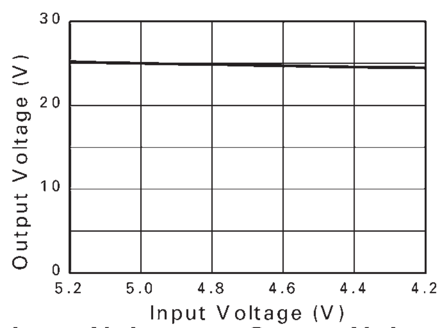
Input Voltage vs Efficiency



Input Voltage vs Output Current



Input Voltage vs Input Current



Input Voltage vs Output Voltage

Europe	Americas	Asia Pacific	Corporate Headquaters
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Design Note 73

ZXSC300 Step down converter for 3W LED

Introduction

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.

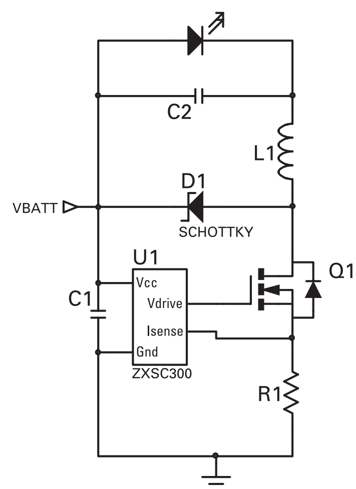


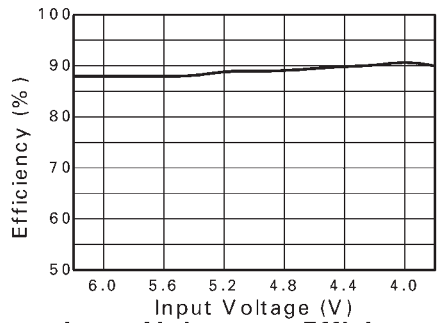
Figure 1

Materials list

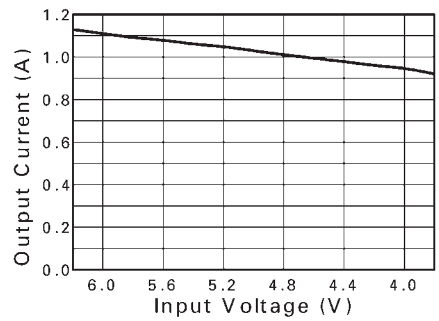
Ref	**Value**	**Part Number**	**Manufacturer**	**Comments**
U1		ZXSC300/310	Zetex	LED Driver in SOT23-5
Q1		ZXMN2A01F	Zetex	SOT23 MOSFET
D1	1A	ZHCS1000	Zetex	1A Schottky in SOT23
L1	22μH	Generic	Generic	I_{SAT} = 3A
R1	20mΩ	Generic	Generic	0805 size
C1	100μF	Generic	Generic	
C2	100μF	Generic	Generic	

Typical operating characteristics

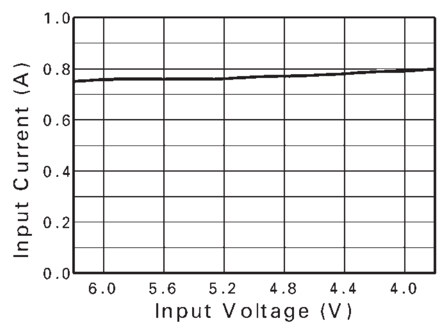
(For typical application circuit where T_A=25°C unless otherwise stated)



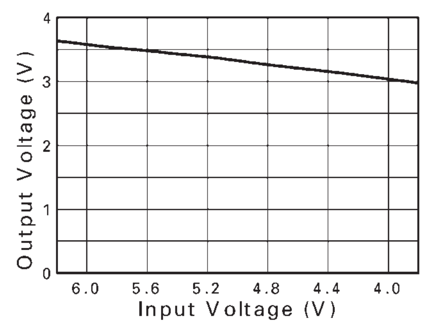
Input Voltage vs Efficiency



Input Voltage vs Output Current



Input Voltage vs Input Current



Input Voltage vs Output Voltage

Europe	**Americas**	**Asia Pacific**	**Corporate Headquaters**
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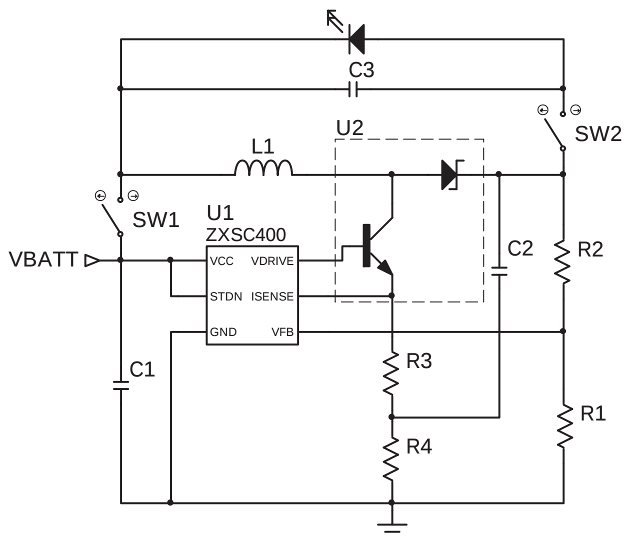
Design Note 74

ZXSC400 Photoflash LED Reference Design

Introduction

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

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.

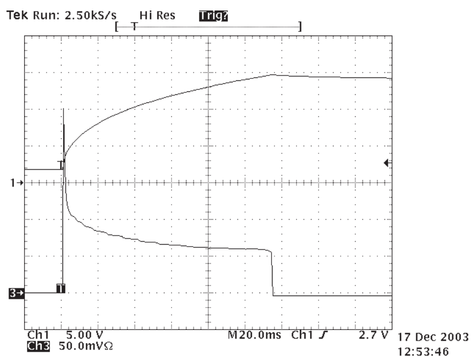
ZETEX SEMICONDUCTORS

Materials List

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	

TYPICAL OPERATING WAVEFORMS

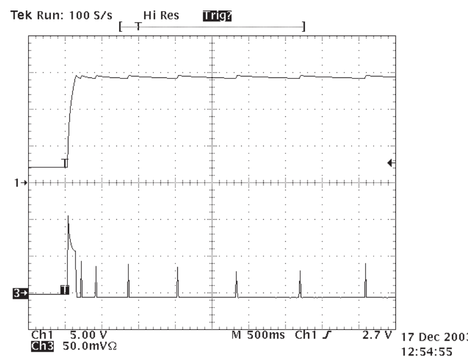
(For typical application circuit where V_{BATT}=3V and T_A=25°C unless otherwise stated)



Charging Mode

Top Trace: C2 Charging

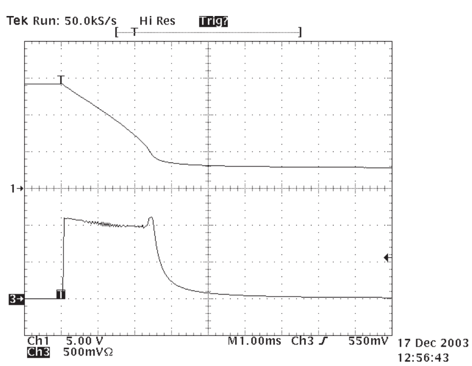
Bottom Trace: Input Current



Refreshing C2

Top Trace: C2 Charging

Bottom Trace: Input Current



Discharging Mode (Flash)

Top Trace: C2 Discharging

Bottom Trace: LED Current

ZETEX SEMICONDUCTORS

Europe	Americas	Asia Pacific	Corporate Headquaters
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ZXSC310 Solar Powered Garden Light Reference Design

Introduction

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.

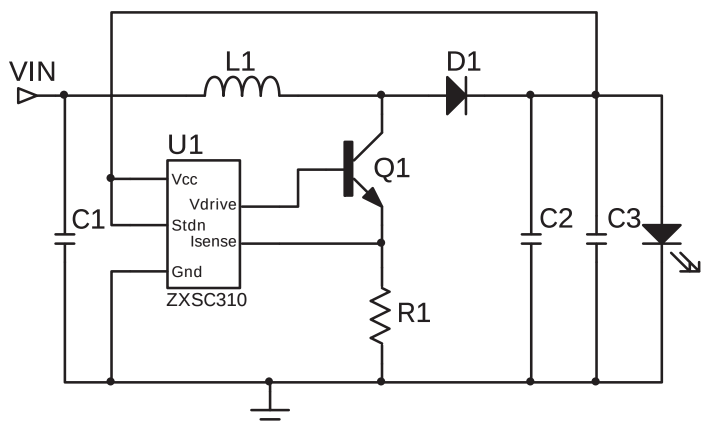

Figure 1

Materials List

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	

TYPICAL OPERATING CHARACTERISTICS

(For typical application circuit where T_A=25°C unless otherwise stated)

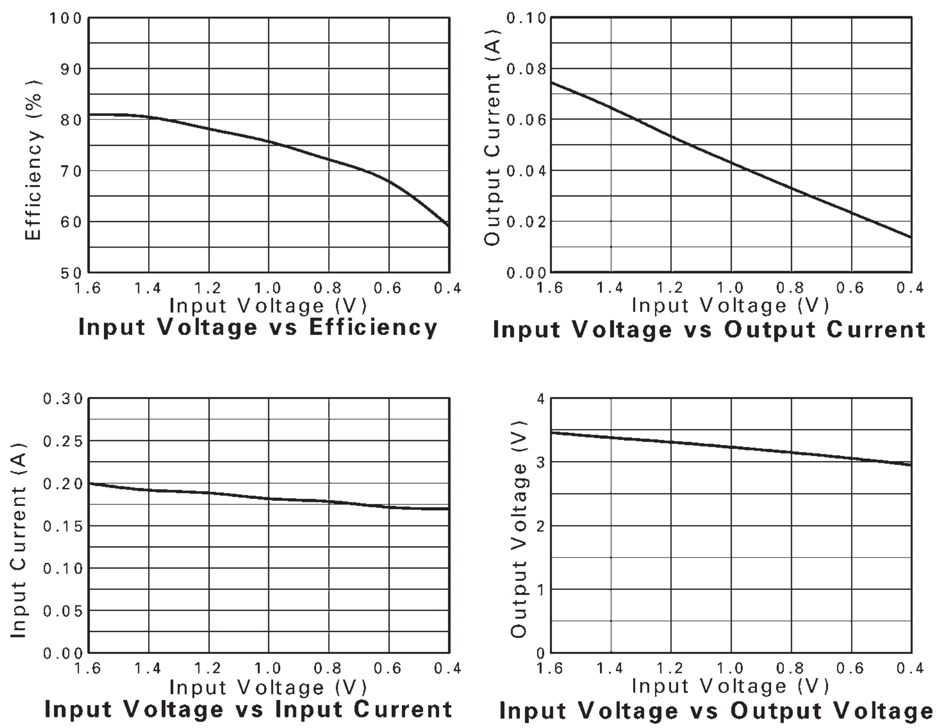

Figure 2

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Design Note 76

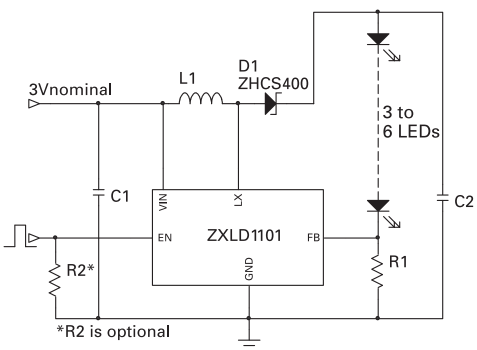
ZXLD1100 and ZXLD1101 driving from 3 to 6 LEDs

Introduction

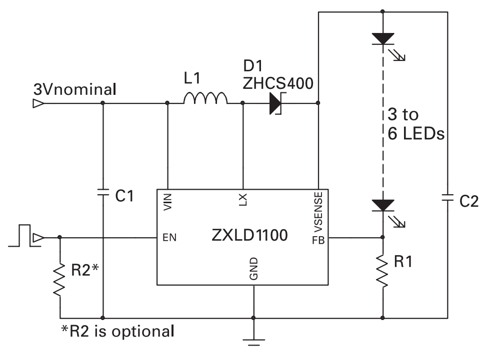
This design note shows the ZXLD1100 and ZXLD1101 driving series connected LEDs. The input voltage range is 2.5V to 5.5V. The same circuit can be used for up to 6 LEDs.

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

Circuit diagram



Circuit diagram



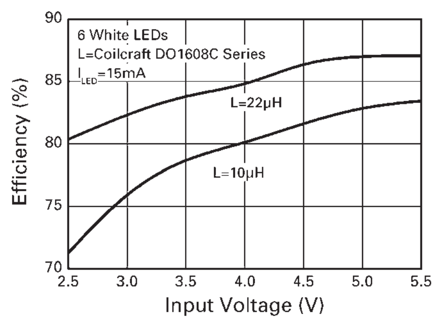
Note: LED current is set to 15mA

Bill of materials

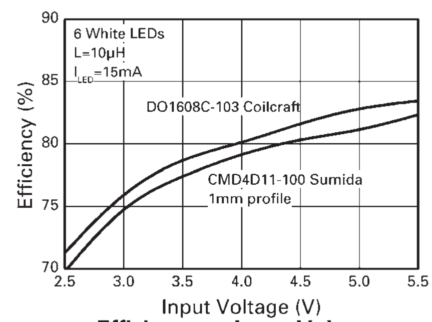
Ref	Value	Package	Part Number	Manufacturer	Notes
U1		TSOT23-5	ZXLD1101ET5	Zetex	LED driver IC
U1		SC706	ZXLD1100H6	Zetex	LED driver IC
D1	400mA	SOD323	ZHCS400	Zetex	400mA Schottky diode
L1	10μH		CMD4D11-100MC	Sumida	1mm height profile
R1	6.8Ω	0603	Generic	Generic	
R2[1]	100kΩ	0603	Generic	Generic	
C1	1μF	0603	Generic	Generic	
C2	1μF	0603	Generic	Generic	
LEDs			NSCW215	Nichia	6pcs per board

Note: R2 is optional. If EN is floating add R2 to shutdown the ZXLD1101 and LEDs. If EN pin can be driven low,R2 is not necessary.

Performance graphs

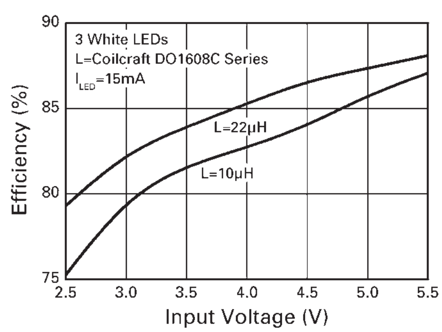


Efficiency vs Input Voltage

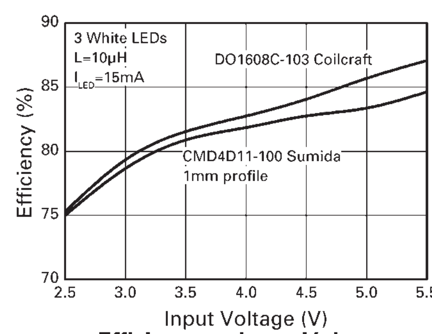


Efficiency vs Input Voltage

Performance graphs



Efficiency vs Input Voltage



Efficiency vs Input Voltage

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Design Note 78

ZXSC310 WITH REVERSE POLARITY PROTECTION

Introduction

The circuit 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

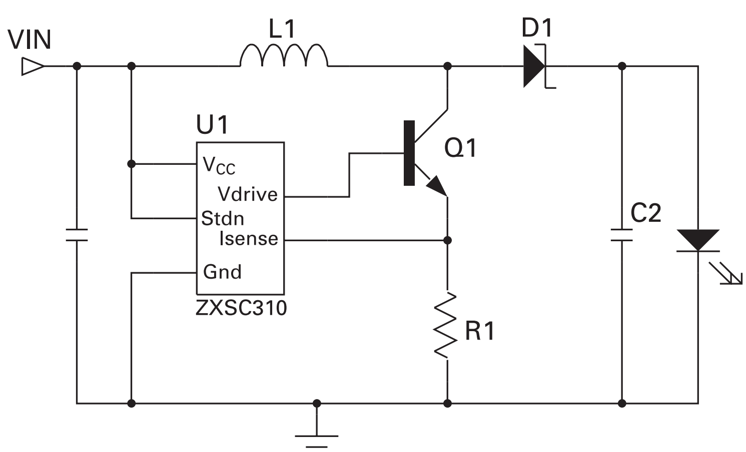
If a negative voltage appears at the input terminal of Figure 1 then reverse current will flow from the ground pin of the ZXSC310 to the V_{CC} terminal and back to battery. This current is high and will damage the ZXSC310. Some of this reverse current will also flow through the V_{DRIVE} terminal of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



Reverse protection without efficiency loss

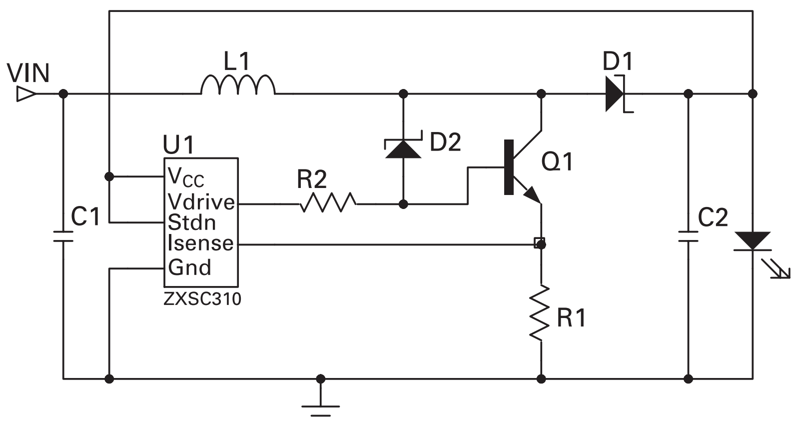
By adding current limiting resistor and Schottky diode,, the reverse current flow can be eliminated without a loss of efficiency.

Torch 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, through L1 and 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

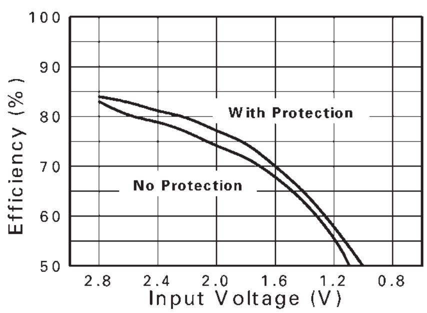


Materials list

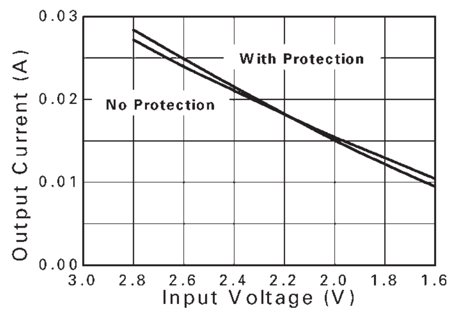
Ref	Value	Part Number	Manufacturer	Comments
U1		ZXSC310E5	Zetex	LED driver in SOT23-5
Q1		FMMT617	Zetex	Low sat NPN in SOT23
D1	1A	ZHCS1000	Zetex	1A Schottky in SOT23
D2(1)	1A	ZHCS1000	Zetex	1A Schottky in SOT23
L1	72µH	Generic	Generic	I_{SAT}>0.5A, R<0.3Ω
R1	260mΩ	Generic	Generic	0805 size
R2(1)	100Ω	Generic	Generic	0805 size
C1	10µF	Generic	Generic	
C2	22µF	Generic	Generic	

(1) Add for reverse protection

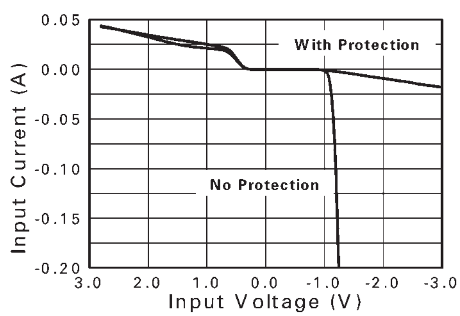
TYPICAL OPERATING CHARACTERISTICS
(For typical application circuit where TA=25°C unless otherwise stated)



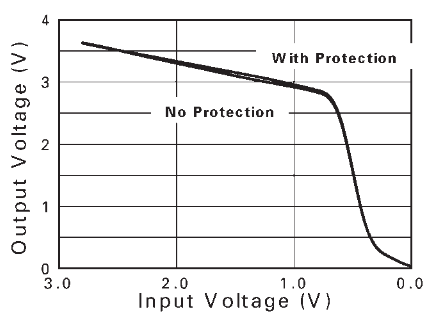
Input Voltage vs Efficiency



Input Voltage vs Output Current



Input Voltage vs Input Current



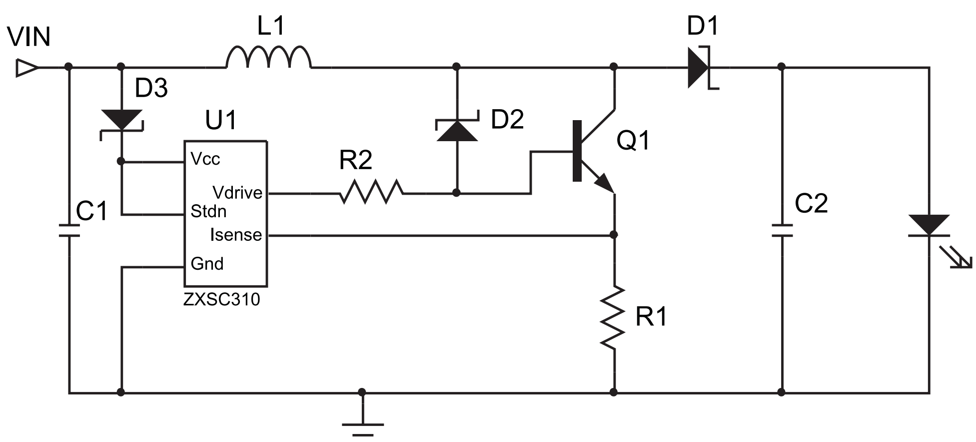
Input Voltage vs Output Voltage

Other circuit examples using reverse polarity protection

Torch circuit without bootstrap

The circuit shown in figure 3 is for an LED torch application without bootstrap. As described previously reverse current can flow from the G_{ND} terminal to V_{CC} and back to the battery. To block this current path an extra diode, D3 is added. It is recommended that a Schottky diode be use for this application to maximize the start-up input voltage from $V_{CC(MAX)}$ to $V_{CC(MIN)}$ + D3 V_F, 3V to 1V. The Schottky diode, D2, and resistor, R2, work in the same way as described in the bootstrap circuit in Figure 2.

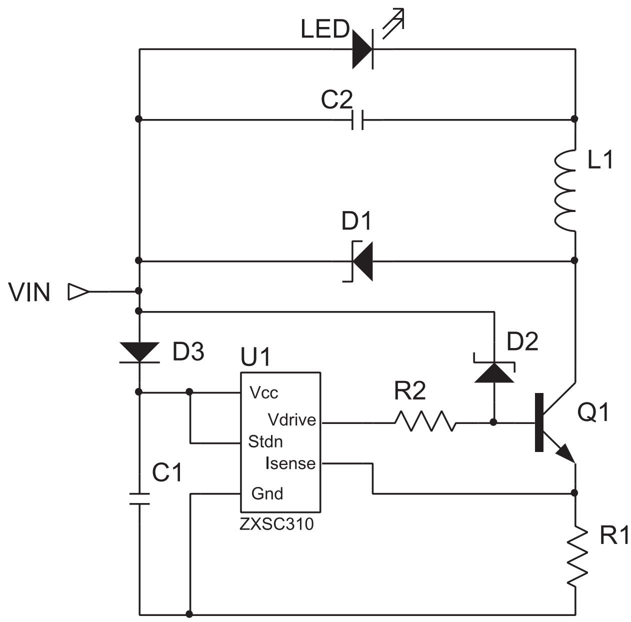
Figure 3



Step down converter for a high powered torch

Figure 4 is a step down converter with reverse polarity protection. The main application for this circuit is a four alkaline cell torch driving a high powered LED. Again the protection circuit operates as described above with the exception of D3. This diode can now be replaced by a low cost signal diode as input voltage is limited to a minimum of 4V.

Figure 4



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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.

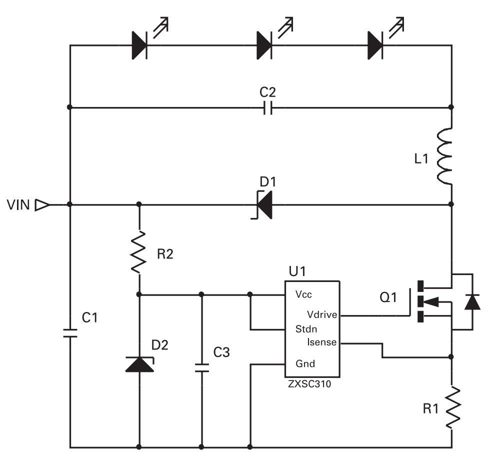


Figure 1

Operation

Please refer to the typical schematic diagram in Figure 1.

On Period, TON

The ZXSC300 turns on Q1 until it senses 19mV (nominal) on the ISENSE pin.

The current in Q1 to reach this threshold is therefore 19mV/R1, called IPEAK.

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 VF. 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 RDS(ON) and R1 always drops less than 19mV, as this is the turn-off threshold for Q1.

VIN = VF + V(L1)

TON = Ipeak x L1/ V(L1)

So TON can be calculated, as the voltage across L1 is obtained by subtracting the forward LED voltage drop from VIN. Therefore, if L1 is smaller, TON will be smaller for the same peak current IPEAK and the same battery voltage VIN. Note that, while the inductor current is ramping up to IPEAK, the current is flowing through the LED and so the average current in the LED is the sum of the ramps during the TON ramping up period and the TOFF ramping down period.

Off Period, TOFF

The TOFF 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 minimise the conductive loss and switching loss, TON should not be much smaller than TOFF. 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 TOFF of 1.7µs, this gives a TON 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 TOFF, 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:

$\frac{1}{2} \times L \times IPEAK^2$ [Joules]

Continuous and Discontinuous Modes (and average LED current)

If TOFF is exactly the time required for the current to reach zero, the average current in the LED will be IPEAK/2. In practice, the current might reach zero before TOFF 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.

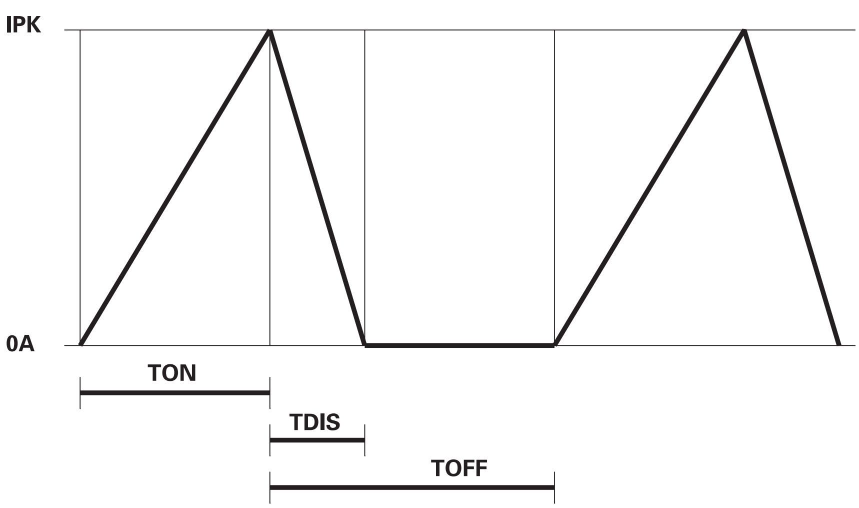


Figure 2

For continuous mode,

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

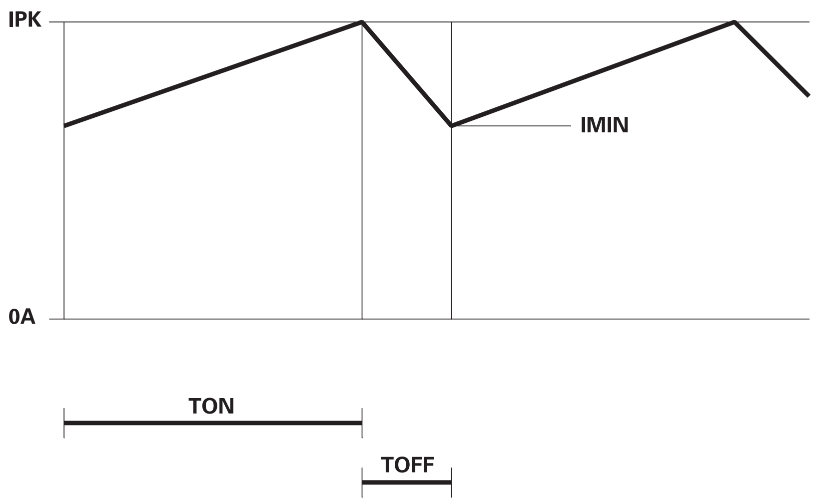


Figure 3

Design Example - Refer to circuit and materials list in Figure 4

Input = VIN = 12V

LED Forward Drop = VLED = 9.6V

VIN = VLED+VL

Therefore VL = (12 - 9.6) = 2.4

The peak current = VSENSE / R1
(R1 is RSENSE) = 34mV/50mW = 680mA

TON = IPEAK * L1/V(L1)

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

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 VIN and VLED 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:

$$TDIS\ \frac{680mA\ x\ 22\mu H}{(9.6 + 0.3)} = 15\mu s$$

As the TOFF 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 TON times. The current can never exceed IPEAK, so even if it starts from a finite value (i.e. continuous mode) it will not exceed the IPEAK. 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 IPEAK and component tolerances).

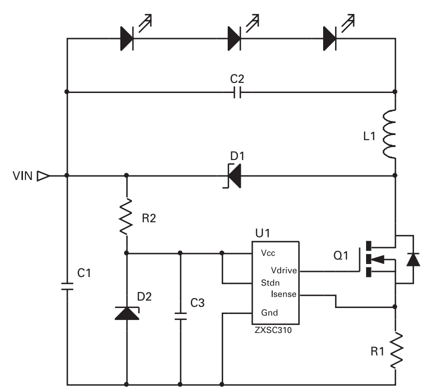
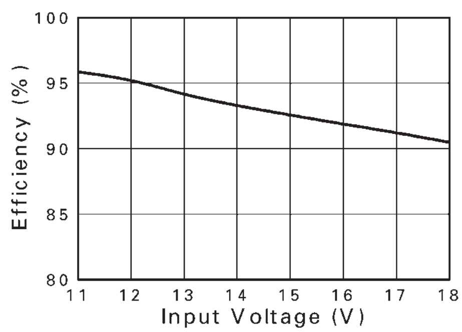


Figure 4

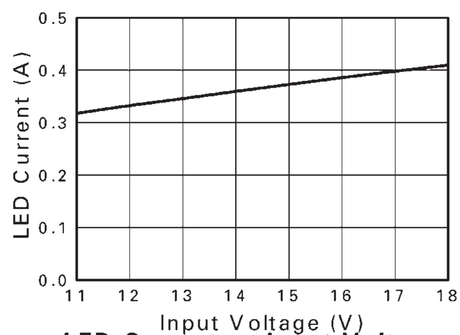
Materials List

Ref	Value	Part Number	Manufacturer	Comments
U1		ZXSC310E5	Zetex	LED Driver in SOT23-5
Q1		ZXMN6A07F	Zetex	N-channel MOSFET in SOT23
D1	1A / 40V	ZHCS1000	Zetex	1A Schottky diode in SOT23
D2	6V8	Generic	Generic	6V8 Zener diode
L1	22µH	DO3316P-223	Coilcraft	
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	

TYPICAL PERFORMANCE GRAPHS FOR 12V SYSTEM



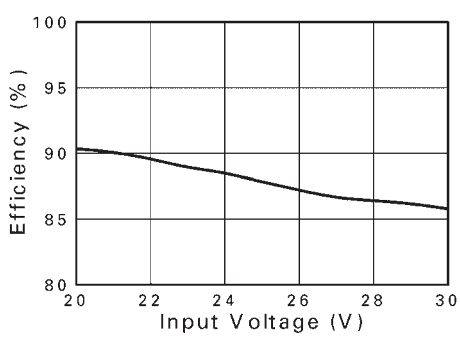
Efficiency vs Input Voltage



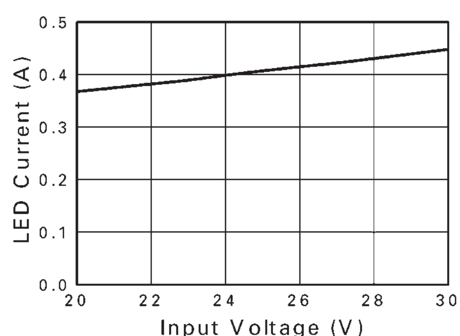
LED Current vs Input Voltage

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



Efficiency vs Input Voltage



LED Current vs Input Voltage

Useful formulae for calculations

The input power from the battery during TON (assuming discontinuous operation mode) is VIN * IPEAK /2. The average input current from the battery is therefore this current multiplied by the ratio of TON to the total cycle time:

$$\frac{IPEAK}{2} \; x \; \frac{TON}{TON + TOFF}$$

It can be seen from this how the average battery current will increase at lower VIN as TON becomes larger compared to the fixed 1.7µs TOFF. 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 * $IPEAK^2$ [Joules]

$$TON = \frac{IPEAK \;\; x \; L1}{(VBATT - VLED)}$$

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 IPEAK 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 IPEAK/2.

As the battery voltage increases, the TON necessary to reach IPEAK will decrease, but the LED power will be substantially constant and it will just draw a battery current ramping from zero to IPEAK during TON. At higher battery voltages, TON 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 VF of the LED is 6Vand VF 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 TON period and therefore does not cause a loss, so the overall percentage loss will depend on the ratio of the TON and TOFF periods. For low battery voltages where TON 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.

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