ZETEX
SEMICONDUCTORS

ZXSC100 single cell DC-DC converter LED driving applications

LEDs are about to take over the world in many lighting applications. Advances in LED technologies mean that for some applications they have become very attractive. One area seeing increased use of LEDs is in flashlights, particularly with the availability of white LEDs. Zetex ZXSC100 single cell DC-DC converter offers an ideal solution to driving white LEDs in flashlights, enabling operation from a single NiCd or NiMH cell.

Why LEDs

There are several reasons why LEDs are favoured over incandescent bulbs. LEDs convert far more of their input energy to light, for instance consider how much energy bulbs waste as heat. Increased efficiency means that batteries will last much longer maintaining their brightness. While a low battery will cause a bulb to dim, LEDs will stay bright. LEDs maintain a constant colour even with low battery voltage and their colour doesn't age, white bulbs often turn yellow as they get older. LEDs withstand shock, vibration and frequent switching, offering lifetimes often over 100,000 hours. Any flashlight made using LEDs can truly last for years.

White LEDs

There are two types here, firstly a combination of red green and blue, or secondly a phosphorus coating on an InGaN blue LED. For the purposes of the featured applications it's the latter method which is discussed. In order to drive this style of white LED typically 3.6V is required and current around 20mA to 50mA, this of course is quite variable depending on the exact LED product chosen.

Why use a DC-DC converter

There are two principle ways of driving LEDs, either continuously or using a pulsed current. A pulsed current is preferred because energy is conserved and the LEDs can appear brighter. By applying pulses, higher current can be driven safely into the LED. Even if the average current is the same, the eye and brain believes the LED is brighter. There is a trade-off to consider in terms of the pulsed current value and duty cycle versus battery life. The ZXSC100 allows optimum performance to be selected.

ZXSC converter solution

The ZXSC100 series is designed for DC-DC applications where step-up voltage conversion from very low input voltages is required. These applications mainly operate from single nickel cadmium or nickel metal hydride battery cells. A typical application circuit is shown in Figure 1.
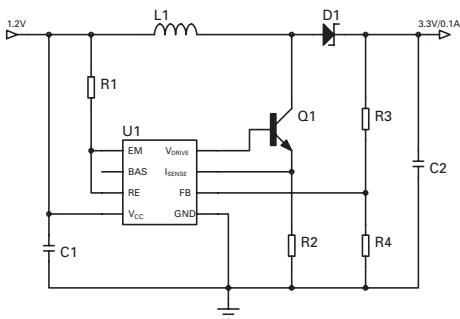

Figure 1
Typical application circuit

The ZXSC devices are non-synchronous PFM, DC-DC controller IC's which drive an external transistor. Zetex SuperSOT4TM switching transistors (ZXT14 series), with saturation resistance as low as 13mΩ, are recommended as the external switching element for very high performance circuits, for white LED driving the FMMT617 is an ideal cost effective alternative. Whichever bipolar transistors are used, the circuit offers high efficiency conversion with input voltages down to below 1 volt.

The non-synchronous circuit can start up under full load with regulation maintained down to an input voltage of only 0.93 volts. The solution configuration ensures optimum efficiency over a wider range of load currents, several circuit configurations are possible with power dissipation up to, and even beyond 2W.

In the conventional DC-DC architecture shown in figure. 1, the step up output voltage is easily programmed with external resistors, the non-synchronous architecture and SuperSOT4™ device enabling an output voltage almost down to the input voltage level. For best performance the ZXSC quiescent current is a small 150µA ensuring minimum battery drain in no load conditions.

ZXSC100 LED lamp driving applications

Many of the features of the circuit shown above make the ZXSC100 solution ideal for LED lamp driving applications from a single cell. In principal conversion from 1.2V to the 3.6V, typically required by white LEDs, is necessary. Load currents in the region of 20mA to 50mA being required for a single LED element.

To minimize size, weight and cost, single cell operation is an advantage. The ZXSC is well matched to single cell NiCd and NiMH characteristics. The circuit will turn on at 1.06V, to maximise the life the battery can offer, the converter does not turn off until the battery voltage falls to 0.93V.

The circuit itself is very simple, a minimum number of components are used and they are all small size. The ZXSC uses the very small MSOP8 package, the pass transistor is SOT23. Depending on the requirements of the circuit several solution configurations are possible. In the following, three such configurations are discussed. The first optimizes battery life, the second

optimizes LED brightness and the third offers a solution using a smaller inductor for applications where higher performance is not required.

Optimum battery life solution

Figure 2 shows a solution optimized for maximum battery life. Its also a very simple circuit requiring an minimum number of external components. No capacitors are required as the circuit stable under all conditions.

The inductor recommended is a low cost miniature component. Its value is chosen to ensure that there is constant current in the inductor, the resulting current level during the LED on pulse shows only a small drop. No compromise is made on efficiency however in this simple solution. In a standard configuration efficiency well over 80% can be achieved. With careful inductor selection efficiency over 90% is possible.

The inherent flexibility of the ZXSC circuit means that parallel or series LEDs can be driven depending on application needs. A simple modification to the application circuit means that the maximum pulse current can be programmed to match the characteristics of the chosen LED load, pulse current in the range 10mA to 3A and beyond can be easily achieved.

Figure 2 shows the ZXSC configured to drive a single LED. Referring to the curves shown in Figure 3, there is a relatively small drop from the peak current through the LED during the discharge period. This maintains the peak light output. To ensure maximum efficiency and battery life the inductor value must be chosen appropriately.

Programmable pulse current

Selection of the LED for the application will determine the peak current for safe operation. Once this is known the circuit can be programmed with this value. The control of peak current is achieved with the appropriate selection of the R_{SENSE} (R2) value. An internal reference, set to 25mV, is connected to the R_{SENSE} pin, which leaves a simple calculation for the resistor value.
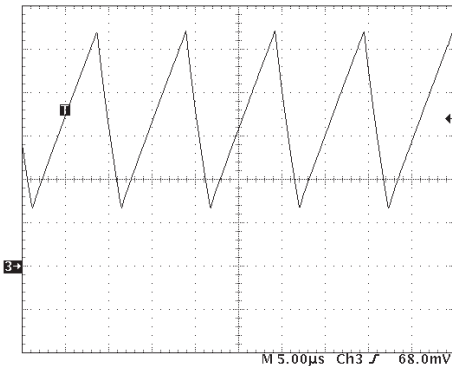
$$I_{PK} = 25mV/R_{SENSE}$$

After turning transistor Q1 on, the inductor current rises until the voltage across sense resistor R_{SENSE} exceeds 25mV. This will terminate the "switch-on" period. The following "switch-off" period has a fixed duration
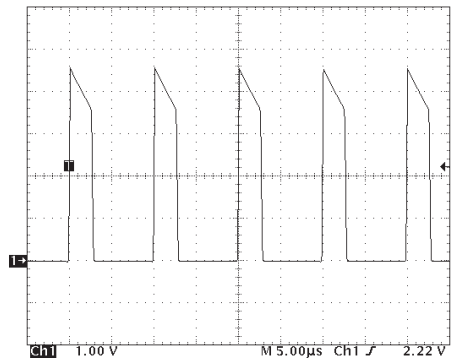

Figure 2
Maximum battery life ZXSC100 LED lamp application
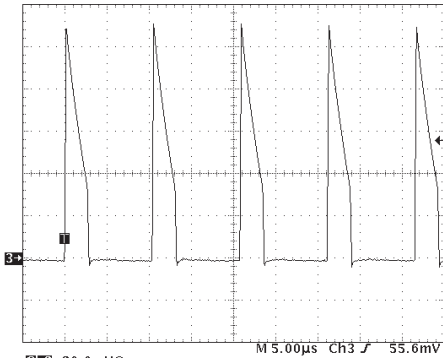
LED Current (20mA/div)
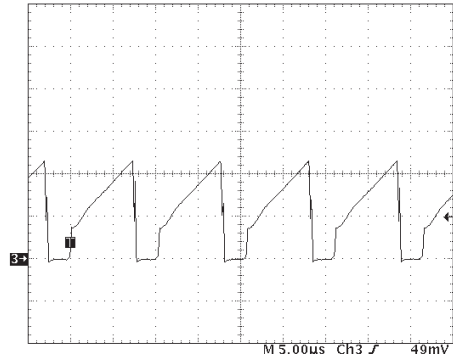
R$_{SENSE}$ Current (50mA/div)

Inductor Current (20mA/div)

Collector Voltage (1V/div)

Figure 3
Maximum battery life ZXSC100 LED lamp waveforms.

of 2.5us set inside the ZXSC IC. The inductor starts discharging into the LED with the same current that was flowing at the end of the "switch-on" period. With this type of operation the LED can be pulsed at the maximum allowed current and brightness without the risk of damage from over-current. Brightness remains constant through battery life.

Pulse current range

The ZXSC100 will work over a wide range of current and output power depending on circuit configuration. Appropriate selection of the external pass transistor allows operating currents from a few mA up to 3A to be programmed. The output voltage can be anything from a minimum of the battery input voltage up to the breakdown voltage of the chosen pass transistor. This means its possible to have many different combinations of LEDs, whether serial or parallel, to suit application needs. Currents up to around 700mA can be driven from a single pass transistor, for currents larger than this an extra PNP small signal drive transistor can simply be added.

Low battery shutdown

An internal shutdown circuit supervises turn-on at 1.06V and turn-off at 0.93V. As the battery cell discharges its voltage will fall, once the 0.93V threshold is reached the converter will shut down.

Efficiency

For the most cost effective solutions, using a standard low cost minimum sized inductor results in efficiencies over 80%. Using a higher performance inductor can see the conversion efficiency exceed 90%. For whichever conditions, to optimise efficiency the inductor should be chosen for minimum resistive and magnetic losses.

Frequency

The circuit shown is operating in continuous mode, the output current is regulated as described above. The switching frequency is determined by R_{SENSE} together with the supply voltage, principally the inductor value does not effect the frequency. A change in inductor value will change the rate of charge and discharge but the period will remain essentially constant.

The discharge period (t_{OFF}) is set within the IC to 2.5us. During this time the discharge current will decrease from the programmed maximum as follows:

$$\Delta I = (I_{PK} - I_{DIS}) = \frac{(V_{OUT} - V_{IN}) \times t_{OFF}}{L1}$$

The charge (t_{ON}) period is:

$$t_{ON} = \frac{(V_{OUT} - V_{IN}) \times t_{OFF}}{V_{IN}}$$

The equations shown do not take into account any losses in the switching transistor or the sense resistor. With the circuit typical operating conditions these can be taken into account and the value of V_{IN} adjusted.

Maximum brightness solution

By adding a rectifier diode and a capacitor, a constant current drive through the LED can be achieved. Whilst efficiency is reduced a little with losses in the Schottky diode, the maximum brightness of the LED can be achieved. Figure 4 shows the ZXSC100 in this configuration.
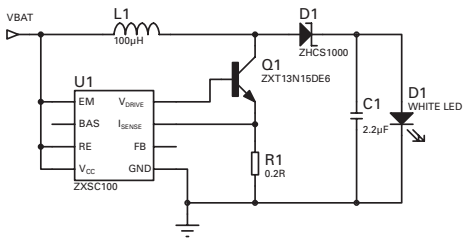
VBAT
L1
100µH
D1
ZHCS1000
U1
EM   V$_{DRIVE}$
BAS   I$_{SENSE}$
RE   FB
V$_{CC}$ GND
ZXSC100
Q1
ZXT13N15DE6
C1
2.2µF
D1
WHITE LED
R1
0.2R

Figure 4
Maximum brightness ZXSC100 LED application

Figure 6 shows the switching waveforms for this applications circuit. As can be seen, with the addition of the rectifier circuit there is a constant current flowing through the LED.

Small inductor solution

Figure 5 shows an application with a smaller 22µH chip coil. This coil can be both smaller and cheaper than with the high performance circuits of Figures 2 and 4, so providing a very small and cost effective solution. The light output may appear less because, with the small inductor, the change in current can be greater than the programmed peak current. This means that there is a complete discharge before the end of the 2.5µs t$_{OFF}$ period and so the LED current will drop to zero. In this case the calculation for t$_{ON}$ is:

$$t_{ON} = \frac{I_{PK} \times L1}{V_{IN}}$$

The associated graph Figure 7 (page 33-8) shows the complete discharge of L1 during the 2.5µs off period followed by harmless coil resonant ringing.
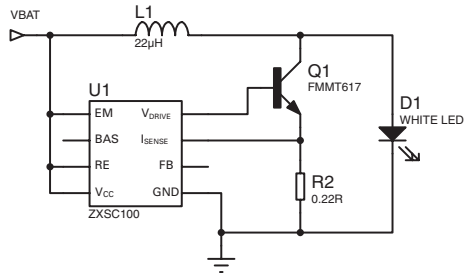
VBAT
L1
22µH
U1
EM   V$_{DRIVE}$
BAS   I$_{SENSE}$
RE   FB
V$_{CC}$ GND
ZXSC100
Q1
FMMT617
D1
WHITE LED
R2
0.22R

Figure 5
Small inductor application

LED Current (10mA/div)

R_SENSE Current (50mA/div)

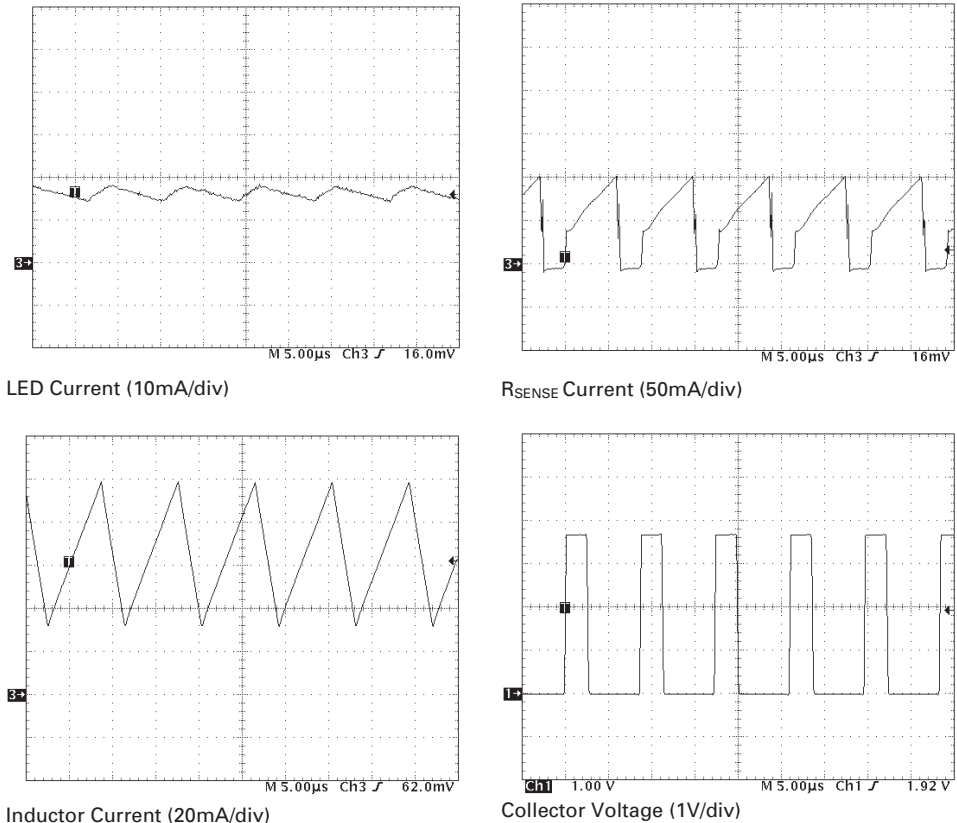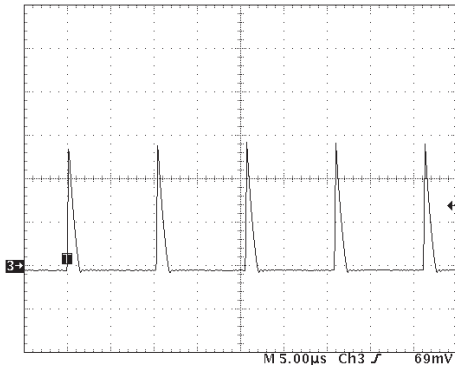Inductor Current (20mA/div)

Collector Voltage (1V/div)

Figure 6.
**Maximum brightness ZXSC100 LED lamp waveforms**

Conclusions

The ZXSC device allows flashlight designers to take advantage of white LEDs in high performance, small size flashlights. The flexibility of the design allows connection of many configurations of LEDs depending on application need.
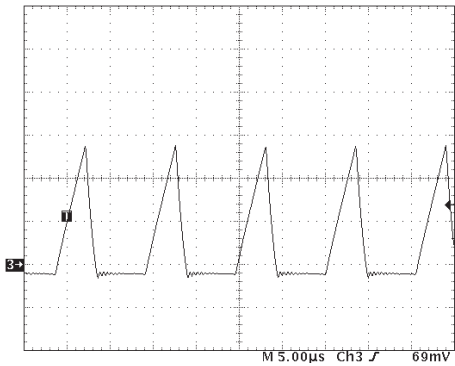
Operation with single cell offers the opportunity for size and cost reduction, the ZXSC's boost capability being ideally matched to single NiMH or NiCd cells.

LED Current (50mA/div)
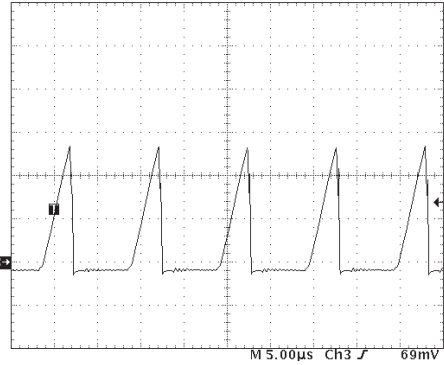
R$_{SENSE}$ Current (50mA/div)

Inductor Current (50mA/div)
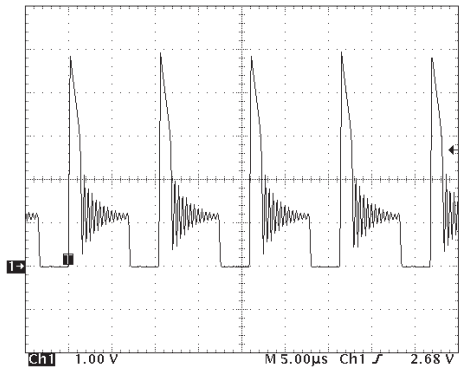
Collector Voltage (1V/div)

Figure 7
Small inductor ZXSC100 LED lamp waveforms

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