AN50
Feed forward compensation for ZXSC300 LED driver

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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.

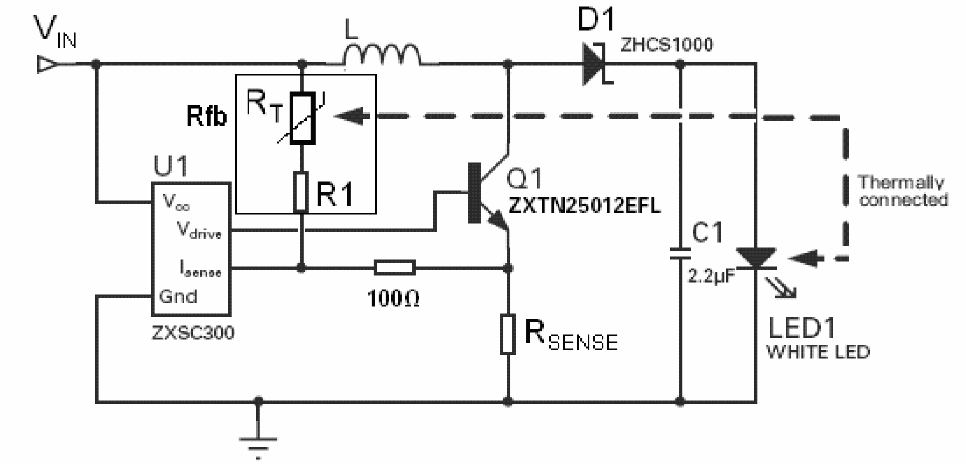

Figure 1 Circuit diagram of ZXSC300 with feed forward and thermal compensation

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

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

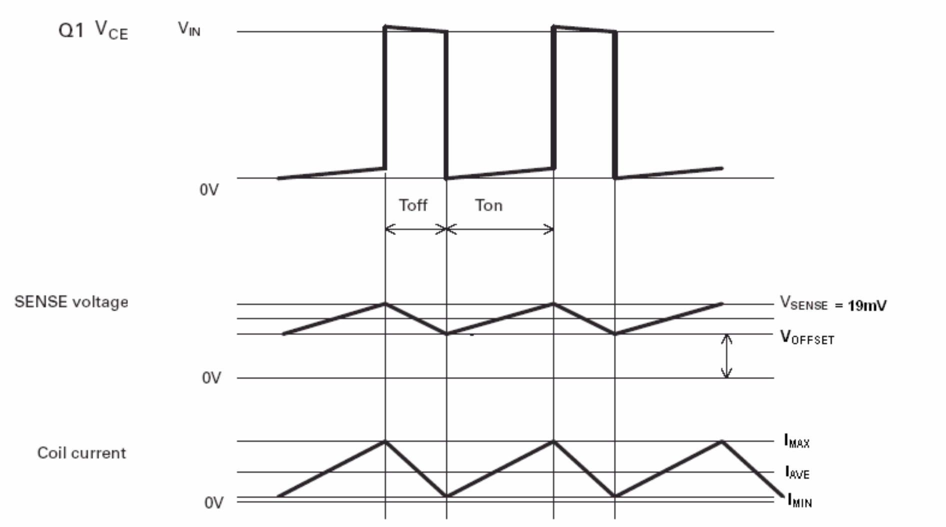

Figure 2 Example of current and voltage waveforms for circuit using ZXSC300 with feed forward network

$I_{AV(VMAX)}$ 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.

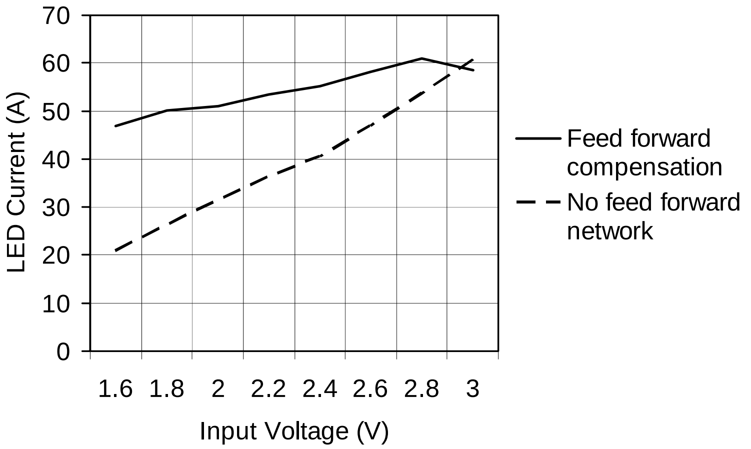

Figure 3 LED current discrepancy for ZXSC300 with feed forward compensation

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.

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