Melexis
Microelectronic Integrated Systems

Application note MLX10801

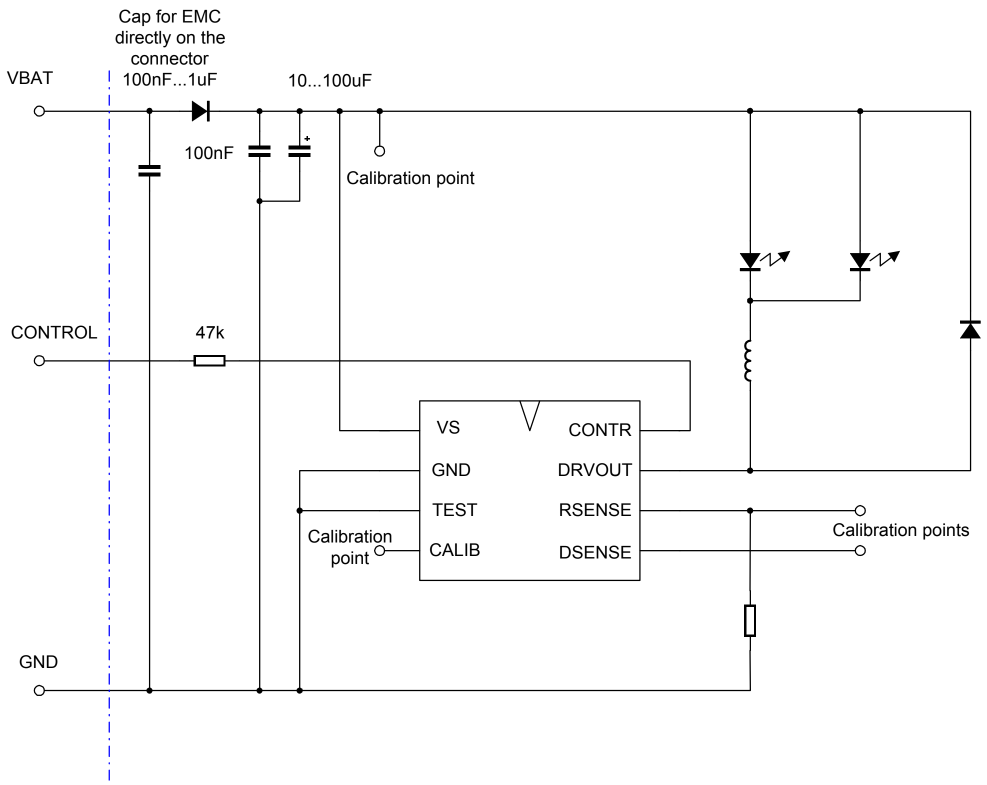
Power LED driver for automotive applications
Power saving low side coil driver
Electronic fuse

1. Scope

The following document describes the use of the MLX10801 on more than 1 LED or with diodes that requires more than 350mA forward current.

2. Application diagrams

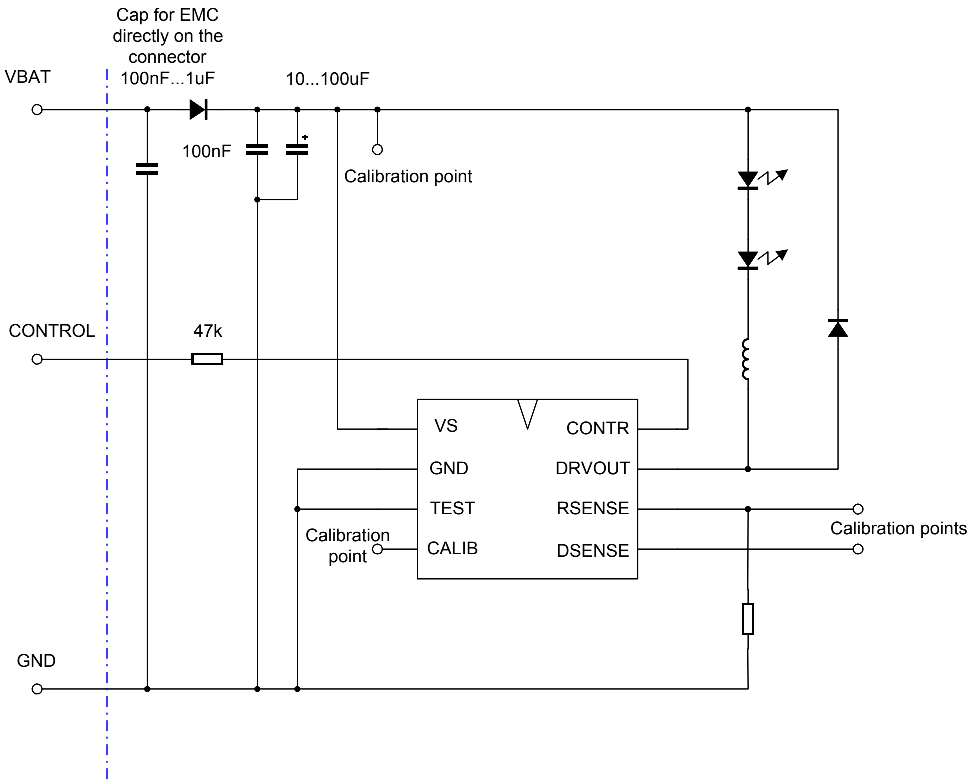
2.1. LEDs connectable in parallel



It is possible to put more than 1 LED in parallel as far as the MLX10801 driver specifications are kept.
This case is interesting, when LEDs with smaller average currents are used than the IC is specified for.
It is also possible to put them in matrixes (so serial and parallel connection of LEDs).
Here also the discussions of chapter 2.2 should be taken into account.

Attention has to be drawn to the binning of the LEDs, means the matching of the forward bias voltages.
In a parallel connection of several LEDs, the LED with the smallest bias voltage at a given current, will clamp the system.
Or in other words, this LED will provide more light output then the others.
This must be compensated by the optical system, or very well matched LEDs must be used.
In a series connection of LEDs this disadvantage is not present.

2.2. LEDs connectable in series



It is possible to put more than 1 diode in series. Attention has only to be drawn, that the current flowing in the series connection of the diodes, stays in the regulation range.
This means, that a peak current, which had been trimmed to the MLX10801 must always be able to flow, so that the driver can regulate correctly.

As long as the circuit stays in regulation mode this will give a higher efficiency to the system

In case VBAT drops down and the trimmed peak current is not flowing anymore, the driver is in saturation and will not switch off anymore, so it is permanently on.

So the minimum VBAT needed for a correct driver operation is calculated for 2 diodes in series as:
VBATmin=Ipeak*(Rds(IC)+R(coil)+Rsense)+Vf(diode)+2*Vf(LED)

Practically calculated with **2 Luxeon white Star LEDs (LXHL-MWxx)**:

Supposed are:

Rds(IC)	1Ohm
R(coil)	1,5 Ohm
Rsense	1Ohm
Vf(diode)	0,8V
Vf(LED)	3,42V

In case a peak current of 500mA and a given trimmed monoflop time had been selected in order to give 350mA average current the following minimum battery voltage can be calculated for a correct work of the driver:
VBATmin=0,5A*(1 Ohm + 1,5 Ohm + 1 Ohm) + 0,8V + 2*3,42V = 9,39 V

In case the voltage drops under the 9,39V as calculated in the sample, the current will be described as
I=(VBAT-Vf(diode)-2*Vf(LED))/(Rds(IC)+R(coil)+Rsense)
Practically means this for instance:
I=(9,38V - 0,8V - 2*3,42V) / (1 Ohm + 1,5 Ohm + 1 Ohm) = 0,497A
This is now a pure DC current and is higher than the selected average current of 350mA.

In case this undervoltage occurs the elements have to carry the following dissipation:

- The sense resistor: Psense = (0,497A)^2 * 1 Ohm = 0,247W
- The coil: Pcoil = (0,497A)^2 * 1.5 Ohm = 0,37W
- The IC: Pdriver = (0,497A)^2 * 1 Ohm = 0,247W.
  With Rth=120k/W for an SO8 package, this is connected to 30 deg. increase of the junction temperature. (This temperature increase is only related to the driver, the dissipation of the IC comes on top of that.)

This has the following impact in case such an undervoltage failure occurs:

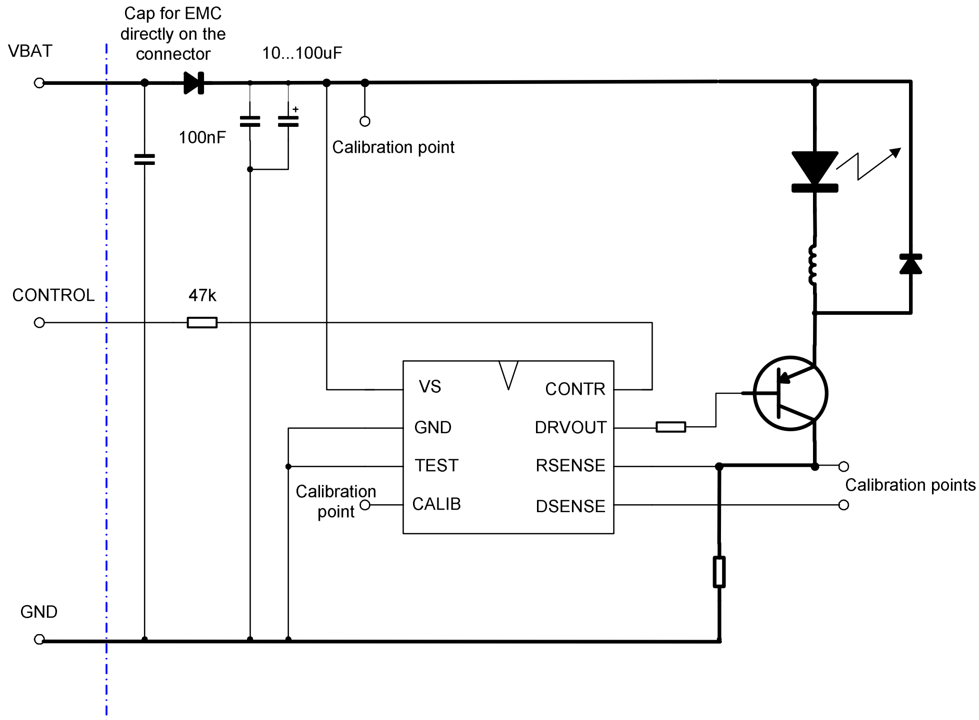
- The LED module increases its light in case the VBATmin point is reached, due to the fact, that the MLX10801 driver is permanently on and not regulating anymore.
- Coil and sense resistor have to be able to dissipate this above calculated energy.
- Due to the fact that the trimmed peak current is adjusted to the max. peak current of the LEDs, the LEDs are not demaged at all. How ever, this condition is treated just as a power down pulse and not steady state condition.
- The MLX10801 driver will not be demaged at all, because it had been designed for this possible undervoltage failure.

In case VBAT still continues to go down, the current and the resulting light output is going down linear as well.

The example shows too, that the headroom for 3 diodes in series is to small for a 12V battery supply used in cars.
VBATmin=0,5A*(1 Ohm + 1,5 Ohm +1 Ohm) + 0,8V + 3*3,42V = 12,81 V

For more detailed Luxeon-LED information, please refer to `http://www.luxeon.com`.

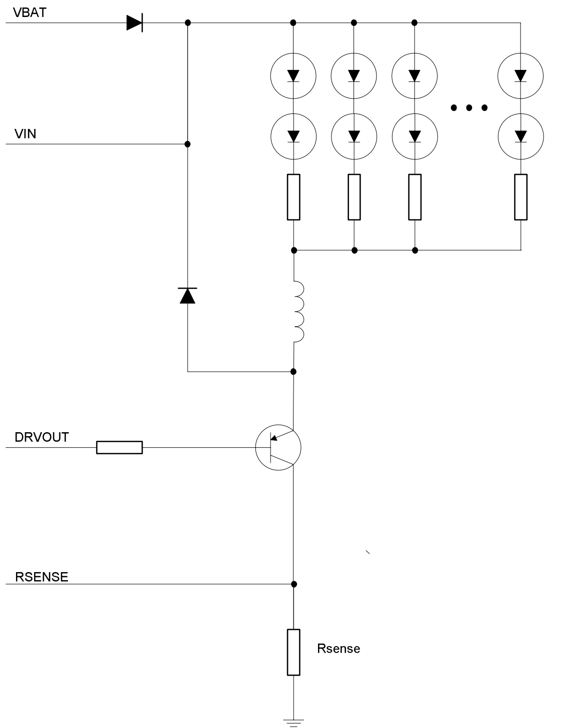
2.3. The MLX10801 and an external driver transistor for very high loads

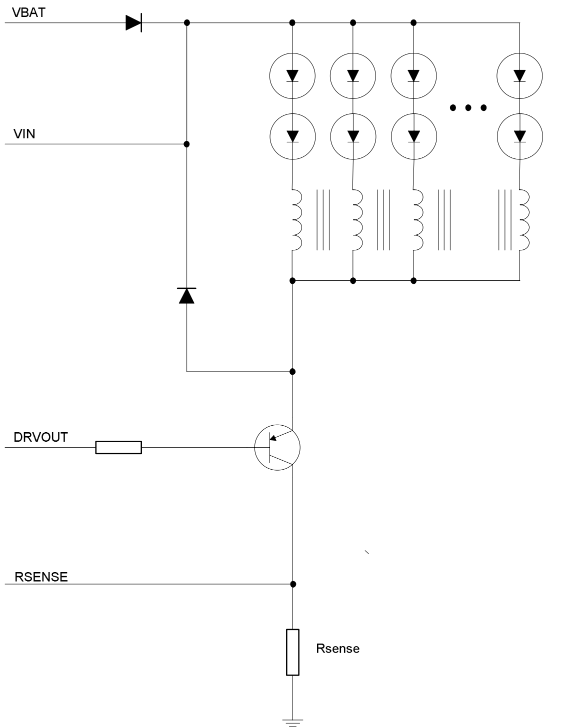


For high loads, which can not be realised using the proposals in chapter 2.1 and 2.2, it is possible to connect an external driving PNP transistor which takes the dissipation. The transistor can be of more or less any type of bipolar PNP power transistor. The above circuit have been tried out with a simple power transistor as BD136. To keep the power loss, and the heat dissipation low, it is recommended to use a transistor with a low Vce during saturation. The transistor has to be driven into saturation or close to saturation depending of transistor type in order to keep the loss as low as possible over the transistor.

In order to drive high loads, the considerations of chapter 2.1 should be taken into account as well. It is problematic to put diodes in parallel if they have differences in forward voltage.

Putting serial coupled pairs in parallel helps in average to minimise the influence of variations in general. Selection of matching diodes is also a solution.





only partial circuit schematic shown

To put a resistor in series with each diode or string of diodes smooth out the variation. Unfortunately this will decrease the efficiency of the system and increased power dissipation. Values have to be chosen depending on the spread of the forward voltage variations of the diodes.

A better solution is to split the coil into one coil for string of diodes. In this case the internal dc resistance of the coils is used as the resistance to smooth variations. The system will then benefit of higher internal resistance and lower inductance of these separated coils.

If the coils the are placed or produced so they have a good inductive coupling, their common inductance will benefit to the charge that is stored during each cycle in the system. This will make the coils smaller and even possible to integrate on the circuit board. This solution have to be tried out and evaluated for each separate application. The principal work, but actual values of the coils inductances and resistances depends of the physical implementation.

3. Efficiency calculations

These examples are given using a efficient bipolar power transistor. A transistor with a Vce saturated of 55mV. If an other transistor is used, it might decrease the voltage margin, making three diodes in series is not possible to use as described.
If the application has to run on a car battery where the voltage can go down to 9V. Having three diodes in series with 3.4V forward voltage drop each will then not be possible using MLX10801 as step down converter. The MLX 10801 can then be used as a voltage up converter instead, se application note MLX10801 Voltage up converter.

3.1. Efficiency calculations 1

The LED is driven by a switched mode power supply using an inductor as the energy storage element. This method has several advantages. The supply voltage has to be set down to the forward bias voltage of the LED. In ordinary applications this is achieved by a resistor or a voltage drop regulator with the following drawbacks:

- A resistor or a simple voltage regulation dissipates power which is transformed to heat
- Efficiency is reduced drastically

A resistor will have also have following drawback:
- The light output of the LED is dependent on the supply and the temperature of the resistor

The MLX10801 avoids these disadvantages as the following calculation shows.

<u>Supposed:</u>

V_{bat} = 13.8V
$V_{fLED} \approx$ 3.4V (typical white light diode)
$I_{fLED} \approx$ 1A
$V_{f1} \approx$ 0.7V (reverse polarity diode)
$V_{f2} \approx$ 0.7V (free wheel diode)
$V_{RSENSE} \approx$ 0.6V (@I_{fLED}, R_{SENSE}=0.6 Ohm)
$V_{ce} \approx$ 0.05V (@I_{fLED})
$V_{Coil} \approx$ 0.2V (@I_{fLED})

<u>Efficiency using a simple resistor or a voltage drop regulator:</u>

Efficiency n, one diode: $n = 1xV_{fLED} / V_{bat} \approx$ **25%**
Efficiency n, two diodes in serie: $n = 2xV_{fLED} / V_{bat} \approx$ **49%**
Efficiency n, three diodes in serie: $n = 3xV_{fLED} / V_{bat} \approx$ **74%**
(Three diodes will not give sufficient voltage margin for variations of battery voltage for any simple voltage regulation)

In addition to lower efficiency and sensitivity to variations of V_{bat} comes the lack of additional functionality like temperature sensing and dimming.

<u>Efficiency using the MLX10801:</u>

The following calculation is an approximation only, due to the fact the coil current is not constant. It is therefore calculated with average currents.

1) During OFF time, the coil acts as the storage element and puts its energy to the free wheel diode and the LED:
   Efficiency n_1, one diode: $n_1 = 1xV_{fLED}$ / $(1xV_{fLED} + V_{f2} + V_{Coil}) \approx 79\%$
   Efficiency n_1, two diodes in serie: $n_1 = 2xV_{fLED}$ / $(2xV_{fLED} + V_{f2} + V_{Coil}) \approx 88\%$
   Efficiency n_1, three diodes in serie: $n_1 = 3xV_{fLED}$ / $(3xV_{fLED} + V_{f2} + V_{Coil}) \approx 92\%$

2) During ON time, current flows through the reverse polarity diode, LED, coil , FET driver and RSENSE, which causes the following voltage drops:

   Efficiency n_2, one diode: $n_2 = 1xV_{fLED}$ / $(1xV_{fLED} + V_{f1} + V_{Coil} + V_{CE} + V_{RSENSE}) \approx 69\%$
   Efficiency n_2, two diodes in serie: $n_2 = 2xV_{fLED}$ / $(2xV_{fLED} + V_{f1} + V_{Coil} + V_{CE} + V_{RSENSE}) \approx 81\%$
   Efficiency n_2, three diodes in serie: $n_2 = 3xV_{fLED}$ / $(3xV_{fLED} + V_{f1} + V_{Coil} + V_{CE} + V_{RSENSE}) \approx 87\%$

3) ON and OFF times are in ratio of roughly 40:60 one diode, 60:40 two diodes; 90:10 three diodes
   Efficiency n:n one diode = $(n_1*0.6 + n_2*0.4) \approx$ **75%** , 69% @ min required supply: ≈ 5.0V
   Efficiency n:n two diodes in serie = $(n_1*0.4 + n_2*0.6) \approx$ **85%** , 81% @ min required supply: ≈ 8.5V
   Efficiency n:n three diodes in serie = $(n_1*0.1 + n_2*0.9) \approx$ **88%** , 87% @ min required supply: ≈ 12V

Measurements have given an efficiency of about 70% with one diode and confirm this estimation. Note, that the ratio of ON and OFF time depends on many factors like supply voltage, coil inductance, forward bias voltage etc. and is therefore an application specific value. For ordinary applications, efficiency ranges from about 65% - 90%.

3.2. Efficiency calculations 2

Efficiency using the MLX10801, optimised coil for 3 diodes and reverse polarity diode omitted

These calculations are valid for an application there the reverse polarity protection is not needed and a **reverse polarity connection to the circuit never will happen.** Approximately 5% of the total loss will always be over that diode!

Supposed:

V_{bat} = 13.8V
$V_{fLED} \approx$ 3.4V (typical white light diode)
$I_{fLED} \approx$ 1A
$V_{f1} \approx$ 0.0V (reverse polarity diode) omitted
$V_{f2} \approx$ 0.5V (optimised free wheel diode)
$V_{RSENSE} \approx$ 0.6V (@I_{fLED}, R_{SENSE}=0.6Ohm)
$V_{CE} \approx$ 0.05V (@I_{fLED})
$V_{Coil} \approx$ 0.05V (@I_{fLED})

1) During OFF time, the coil acts as the storage element and puts its energy to the free wheel diode and the LED:
Efficiency n, three diodes in serie: $n_1 = 3xV_{fLED} / (3xV_{fLED} + V_{f2} + V_{Coil}) \approx 95\%$

2) During ON time, current flows through the reverse polarity diode, LED, coil , FET driver and RSENSE, which causes the following voltage drops:

Efficiency n_2, three diodes in serie: $n_2 = 3xV_{fLED} / (3xV_{fLED} + V_{f1} + V_{Coil} + V_{CE} + V_{RSENSE}) \approx 95\%$

3) ON and OFF times are in ratio of roughly 50:50 one diode;

Efficiency n:n three diodes in serie = $(n_1*0.5 + n_2*0.5) \approx$ **95% !!!,** 95%@ min required supply: ≈ 11V

This is a calculation of very optimised values, but it show what is achievable! Using MLX10801!

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