LITIX™ Power TLD509xEP/TLD5190QU/TLD5190QV

Slow switch for multiple light functions

About this document

Scope and purpose

Scope of this application note is to give some hints on how to design a slow switch for lighting application in automotive environment.

For cost effective solutions, one DC/DC only could be used to supply multiple functions that are selectable via slow switch.

LITIX™ Power devices are controller for DC/DC converters qualified for automotive applications that fit the market requirements to provide efficient and easy to use solutions. Slow switch approach used with LITIX™ Power devices are a good solution for high beam and low beam in front head lamp. Moreover, for 2-wheeler applications, it is possible to address also three functions (high beam, low beam and daytime running light) with one LITIX™ Power device with two slow switches.

Intended audience

Hardware engineers

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1 Introduction

Today in LED automotive applications cost pressure is getting higher than ever. For this reason a solution to drive two or more functions with one DC/DC is becoming a crucial point. A solution to do that is to put the LED strings in series and by-passing the part of the load that has not to emit light. However, when abruptly shorting a part of the LED string generates a current spike on the remaining part of the LED connected to the output of the DC/DC. Such current spikes can be avoided by using slow switches that are absorbing the energy in excess.

The solution proposed hereafter can be applied to asynchronous DC/DC (based on TLD5097EP, TLD5098EP and TLD5099EP) and also to synchronous DC/DC (based on TLD5190QU and TLD5190QV).

2 Circuit behavior

The output voltage of an LED driver is sum of the individual LED string forward voltages. When one string is getting short-circuited, the initial voltage of the output capacitor remains constant. As the remaining LED string has a lower forward voltage, an overcurrent is observed at the load side until the DC/DC converter regulates the target current again.

Repetitive current spikes could damage the LED or reduce the overall reliability. To avoid this unwanted spikes, a dumper has to be used. The basic idea is to increase the switching time of the MOS that shorts part of the LED string.

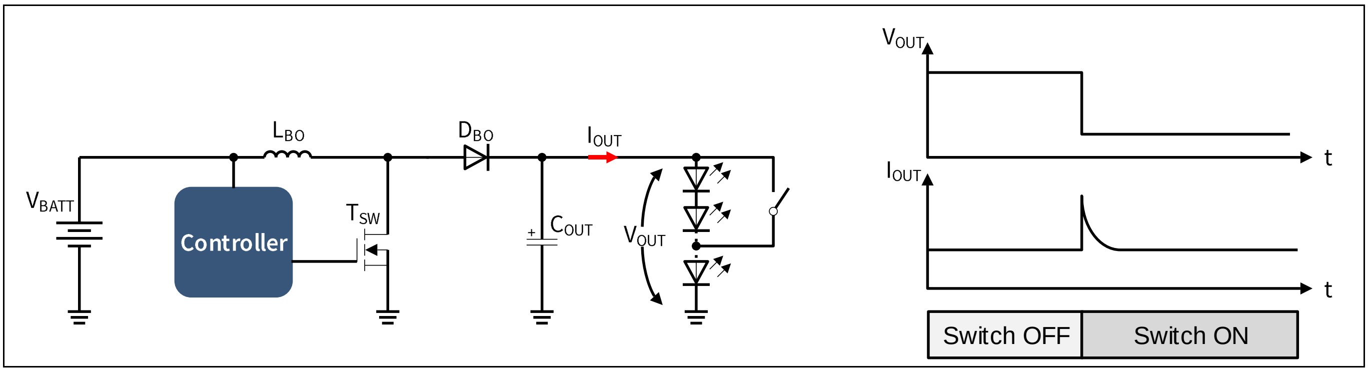


Figure 1 **Simplified schematic of single DC/DC for high beam and low beam application**

The turn on time of the bypass transistor influences directly the maximum amplitude of the spike. When the bypass transistor is shorted, the spike current sustained by the output capacitor can be described by the following Equation 1

$$I_{spike} = C_{OUT}\frac{dV}{dt}$$

Equation 1.

The faster the device switches, the higher the spike will be.

3 MOSFET switching performances

To better understand the performances of the MOSFET a basic analysis is proposed to explain what is happening when the device is used as switch.

For simplicity, N type MOSFET is taken as a reference; for the pMOS, opposite sign of voltage and current have to be taken into account.

The device can be sketched as an RLC network plus voltage controlled current source as reported on the left side of Figure 2, while on the right side, a typical time response of the MOSFET is depicted. The driver circuit is sketched with a current source I_{TEST}.

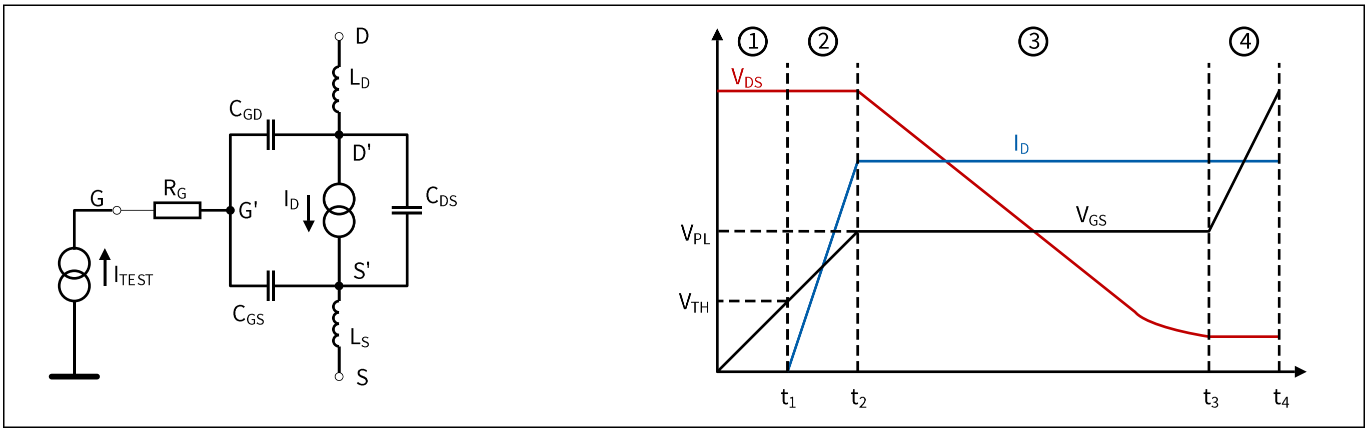


Figure 2 Basic MOS model and turn on waveforms

At t = 0 the gate G is charged from the driver with constant current I_{TEST} and V_{GS} starts to increase linearly. At t_1 the threshold voltage V_{TH} is reached and the current I_D starts to flow.

During the period from t_1 to t_2, C_{GS} continues to be charged, the gate voltage continues to rise and drain current increases proportionally.

At time t_2, V_{GS} reaches the plateau V_{PL}, C_{GS} is completely charged and the drain current touches the predetermined current I_D and stays constant while the drain voltage starts to fall.

With reference to the equivalent circuit model of the MOSFET, it can be seen that with C_{GS} fully charged at t_2, V_{GS} becomes constant and the drive current starts to charge C_{GD} (also called Miller capacitance) until time t_3. Charge time for the Miller capacitance is larger than the one of the gate to source capacitance C_{GS} due to the rapidly changing drain voltage between t_2 and t_3 (current = C dv/dt). The region between t_2 and t_3 is also called Miller plateau. Once both of the capacitances C_{GS} and C_{GD} are fully charged, gate voltage (V_{GS}) starts increasing again.

For BSP170P, the turn on time (from t_0 to t_4) is in range of 20 ns. This means that with C_{out} = 20 uF and just one LED shorted (3.5 V forward voltage), the theoretical I_{spike} is about 3500 A! Of course this value is not reached on boards due to parasitic effects on MOSFET and PCB. Reasonable measured current is in range of 10 A with parasitic inductors of few tens of nH.

4 Switching time

A way to increase the switching time is to increase the Miller capacitor by adding an extra capacitor between gate and drain pins. A proposed circuit for a pMOS is shown in Figure 3

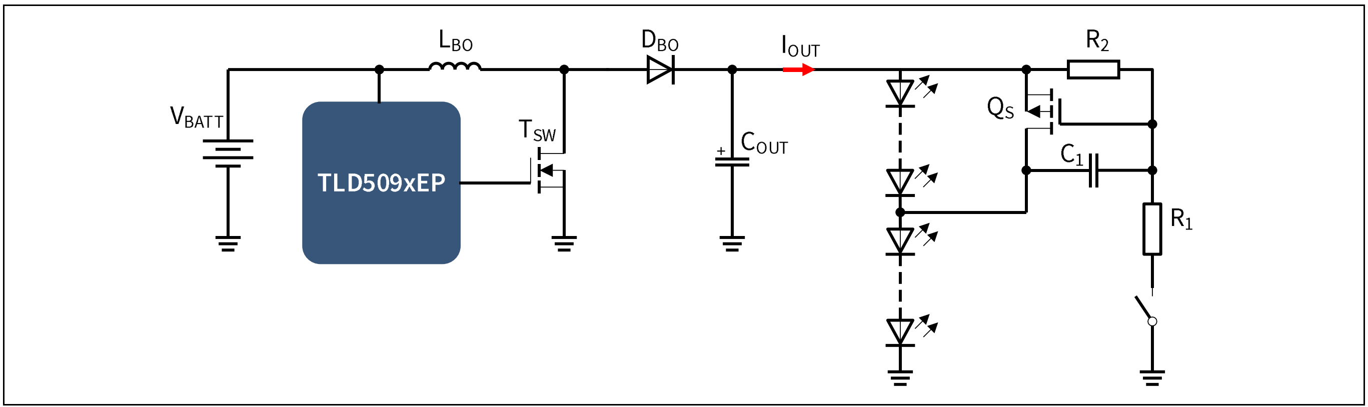


Figure 3 Slow switch approach to drive high beam and low beam with one DC/DC

In the application, the string is divided into two sections and a pMOS Q_S shorts the top of the string. On the bottom of the string there is also an nMOS (not shown in Figure 3 for clarity) to short the remaining part of the string. A digital selector ensures that both devices are not in conduction mode simultaneously. By closing one of the MOSFET, a current spike is produced due to the forward voltage of LED string changes.

To help the reader during the design, this application note explains the selection of the Miller capacitor of pMOS. The same steps are required to select the Miller capacitor of the nMOS that has to be put across the bottom of the string.

The first step is to design the resistor divider that controls the gate voltage during the switching phase. The gate voltage has to be higher than threshold voltage V_{TH}, but lower than the maximum tolerable by the device ($V_{GS,max}$).

$$V_{TH} > \frac{R_1}{R_1 + R_2} \cdot V_{OUT} > V_{GS,max}$$

Equation 2.

R_2 is a pull down resistor. A reasonable value is in the range from 1 kΩ to 10 kΩ to limit the current less than 1 mA. R_1 is calculated according to the value of R_2 and the Equation 2.

Considering to have a maximum spike I_{spike}, and including it as input data for Equation 1, it is possible to calculate the duration of switching time

$$\Delta t = \frac{C_{OUT}}{I_{spike}} \cdot \Delta V_{OUT}$$

Equation 3.

Selecting C_1 such that it is much larger than $C_{GD} + C_{GS}$, the voltage $v_{GS}(t)$ of pMOS is dominated by the external capacitor. To dump the energy in excess on the output capactor, the region with constant current I_D and decreasing voltage V_{DS} (Miller plateau) has to be stretched to a value longer than Δt of equation 3.

The expected voltage step for the source S is ΔV_{OUT}. In the Miller plateau, the voltage between the gate G and the source S is fixed to V_{PL}. This means that in this region, if the source S has to step down of ΔV_{OUT} and the same step has to be done by the gate G.
In this region, the constant time associated to the C_1 is only R_1 because the voltage across R_2 is kept stable to V_{PL}. Nevertheless R_2 impacts on the discharging time because it provides an extra current to R_1. This leads to the following equation of $v_G(t)$ (valid only in the region 3 of Figure 2).

$$v_G(t) = \left(V_D + \Delta V_{OUT} - \frac{|V_{PL}|}{R_2} \cdot R_1\right) \cdot \left(e^{-t/R_1 \cdot C_1}\right) + \frac{|V_{PL}|}{R_2} \cdot R_1$$

Equation 4.

The time needed to perform the $-\Delta V_{OUT}$ step is calculated by

$$t_{slow\_switch} = -R_1 C_1 \ln\left(\frac{V_D - \frac{|V_{PL}|}{R_2} \cdot R_1}{V_D + \Delta V_{OUT} - \frac{|V_{PL}|}{R_2} \cdot R_1}\right)$$

Equation 5.

Combining Equation 3 with Equation 5 and fixing the maximum admissible I_{spike} for the application, it is possible to calculate the value of C_1.

$$C_1 = -\left(\frac{C_{OUT}}{I_{spike}} \cdot \Delta V_{OUT}\right) / R_1 \ln\left(\frac{V_D - \frac{|V_{PL}|}{R_2} \cdot R_1}{V_D + \Delta V_{OUT} - \frac{|V_{PL}|}{R_2} \cdot R_1}\right)$$

Equation 6.

In order to avoid parasitic oscillations, a resistor R_3 has to be added in series to C_1. The value for the resistor R_3 has to be much lower than R_1 (usually, few Ohm is good enough to dump the oscillations). The final solution is shown on Figure 4

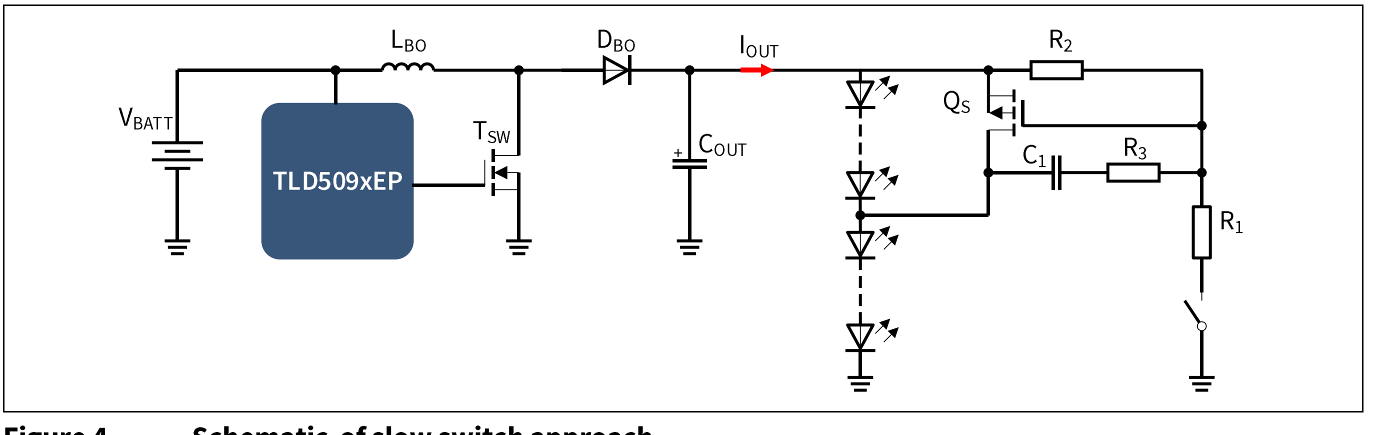


Figure 4 Schematic of slow switch approach

During switching on phase, the pMOS Q_S has to dump the extra energy on the output capacitor C_{OUT} due to the change of output voltage. The power MOSFETs are devices that works fine in ON state and OFF state. They are not able to sustain certain current and voltage for a long time. These performances are highlighted on a SOA chart (Safe Operating Area chart). On this chart, it is possible to check if the device is able to handle the total amount of energy. On the "x" axis there is the operating voltage, while the current is on "y" axis. In the described application condition, the operating voltage is the difference in forward voltages of the complete and the partial LED string, while the current is the I_{spike} generated during the switching time.

5 Implementation

The approach described in previous sections has been used to design the evaluation board TLD5190_2W. This board is intended for 2-wheeler application, where 2 strings enable 3 light functions. Two selectors activate high beam (HB) or low beam (LB); the daytime running light (DRL) is always activated if there are no inputs on the selectors.

The device used on this board is TLD5190QU that is a four switches buck boost controller. Having a synchronous converter helps to increase the system overall efficiency and then reducing the PCB size and heatsink weight.

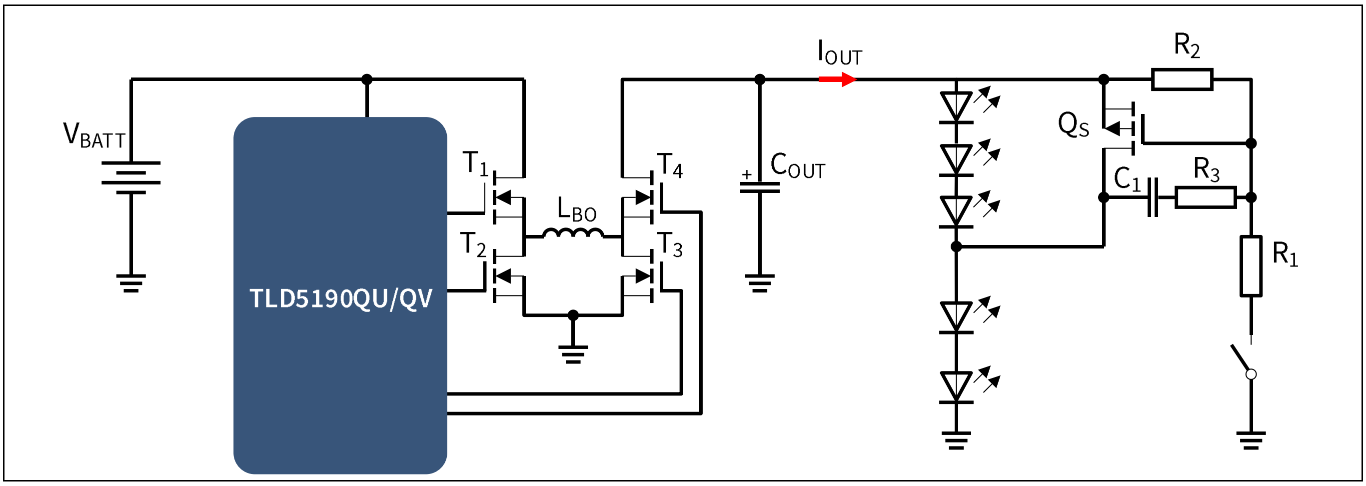


Figure 5

The LB is implemented with a 3 LEDs string, while a DRL has 2 LEDs in series; HB is realized putting all 5 LEDs in series. The system does not show any problems when the load changes to a string with higher number of LEDs.

Nichia NCSW170DT supplied at 1 A is used as reference LED in this design. The main characteristics are summarized in the following Table 1

Table 1 Electrical characteristics of Nichia NCSW170DT

Maximum forward voltage V_f	Maximum forward current	Peak current (pulse width < 10 ms)
3.25 V	1.2 A	1.5 A

The changes of the output voltage when switching on/off light functions is summarized Table 2:

Table 2 Voltage scenario for different light functions

Light function change	LED by-passed	Voltage step
From LB to DRL	1	3.25 V
From HB to LB	2	6.5 V
From HB to DRL	3	9.75 V

The worst case step is then 3 LEDs when the headlamp is switched from HB to DRL.

The DC/DC has 10 uF as output capacitor and BSP170P is used as slow switch (V_{TH} = - 3 V, V_{PL} = -4.34 V).

From this data, it is possible to properly design the slow switch.

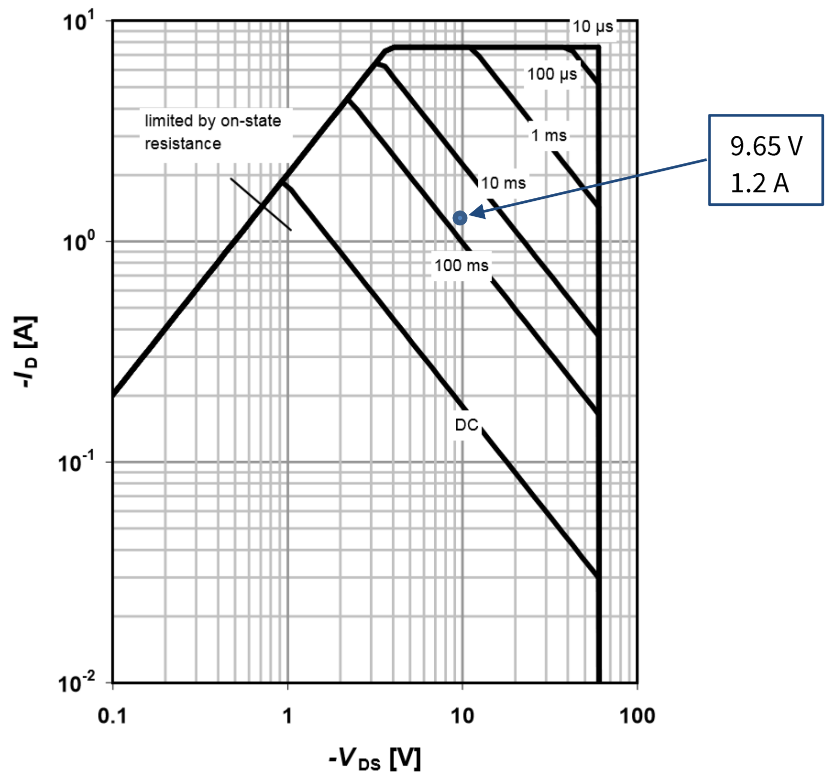
As first step, 10 kΩ pull down resistor is chosen. Then 2.2 kΩ as R_1 resistor ensures proper V_{GS} voltage to the switch (the Vout at steady state is 6.5 V when 3 LEDs are shorted, than the gate has to be lower than 3.5 V).

Imposing 1.2 A as maximum for the current spike, and applying the Equation 6 it is possible to calculate C1

$$C_1 = -\frac{\left(\frac{C_{OUT}}{I_{spike}} \cdot \Delta V_{OUT}\right)}{R_1 \ln\left(\frac{V_D - \frac{|V_{PL}|}{R_2} \cdot R_1}{V_D + \Delta V_{OUT} - \frac{|V_{PL}|}{R_2} \cdot R_1}\right)} = -\frac{\left(\frac{10\ \mu F}{1.2\ A} \cdot 9.75\ V\right)}{\left(2.2\ K\Omega \cdot ln\left(\frac{6.5 - \frac{4.34V}{10\ K\Omega}\ 2.2\ K\Omega}{6.5 + 9.75\ V - \frac{4.34\ V}{10\ K\Omega}\ 2.2\ K\Omega}\right)\right)} = 36.4\ nF$$

The first next value for C1 is 47 nF. To dump parasitic oscillation a 4.7 Ω resistor is used in series to C1.

With this component selection, the time needed to switch is about 105 µs. With this timing the application works according the SOA.



6 Conclusions

In many automotive applications, there is a demand to manage multiple light functions with single DC/DC in order to reduce the overall cost of the system. Shorting part of the LED string causes an excess energy of the output capacitor which is discharged from the LEDs that remain connected (current spike). To reduce this spike, the energy must be dumped on the switching element, increasing the switching time.

In this application note, a slow switching approach has been described with a practical example related to the LED headlamp for two-wheeler vehicles.

Revision history

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