

An Universal Current Limiter

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Introduction

To protect the user as well as the electronic circuit itself, every power supply needs some kind of current limitation. For example, linear regulators have an over temperature shutdown and buck converters measure the voltage drop on a shunt, the FET or inductor. If the output current is higher than a certain threshold, the load is disconnected from the converter for a certain time or it goes into current limitation where the output current stays constant but the output voltage is reduced.

On a boost converter, a diode connects the output directly with the input. Even when it is not switching, the input voltage remains on the output. As the diode can not be switched off, no current limitation is possible by the converter itself. Another problem exists on flyback converters with several isolated output windings. In this case, only one voltage can be regulated, the other ones are free-running with the same duty cycle. If the regulated output is shorted, the controller reduces the duty cycle to protection the power stage. But this causes also all the other outputs to drop and practically the converter delivers no more power on any output.

For these two examples and all applications where a voltage is accessible for a user, an additional current limitation is needed. This article shows how to utilize a LED driver IC as current limiter, if the converter or voltage source has not protection itself.

The Idea

It can rise to the question of why using a LED driver as current limiter. The reason for this is that it exactly fulfills all requirements. Basically, a LED driver is a current source. It does not control the output voltage as “normal” converters do, but it regulates the output current. Therefore the voltage is a consequence of the current and in theory it can have any value. As long as the current is lower than set, the duty cycle of the convert is increased. When the nominal current is achieved, the duty cycle stays at its actual value. Increasing the load further reduces the duty cycle to keep the current constant and to reduce the output voltage at the same time. If the nominal output current is never achieved, the duty cycle increases until it reaches its limit of 100%. This behavior enables a LED driver to use as a current limiter in different applications.

Generally, all buck based ICs can be used, but they have to fulfill three main requirements. First, the IC must be able to operate at 100 % duty cycle. Therefore almost all N-FET based bucks can not be used, as they have to switch the low side FET from time to time to recharge the bootstrap circuit which drives the high side FET. Bucks using a P-FET are the right choice as they can operate at truly 100 % duty cycle. Second, the IC must have current sensing on the high-side, means in front of the output. If the output is accessible for a user, the return path is usually ground, so a shunt between the return path and ground is not possible. And third, the current sense threshold should be low to cause only a minimum of voltage drop on the shunt without having a too big influence on the output voltage at full load.

All these requirements are fulfilled by the LM3409. Additionally, it has a small size (10-MSOP) and needs only a minimum of external parts.

Constant Current Mode

When designing the IC as a LED driver, it behaves like a current source. If the output current is below the threshold value, the duty cycle is 100 %. At a higher load, the duty cycle is reduced to keep the current constant but to decrease the output voltage at the same time. This behavior remains the same until the output voltage reaches 1.24 V. This is the minimum output voltage a converter based on the LM3409 can deliver. Below that, the converter is switched off for a certain time until it restarts.

Figure 1 shows the schematic for constant current mode.

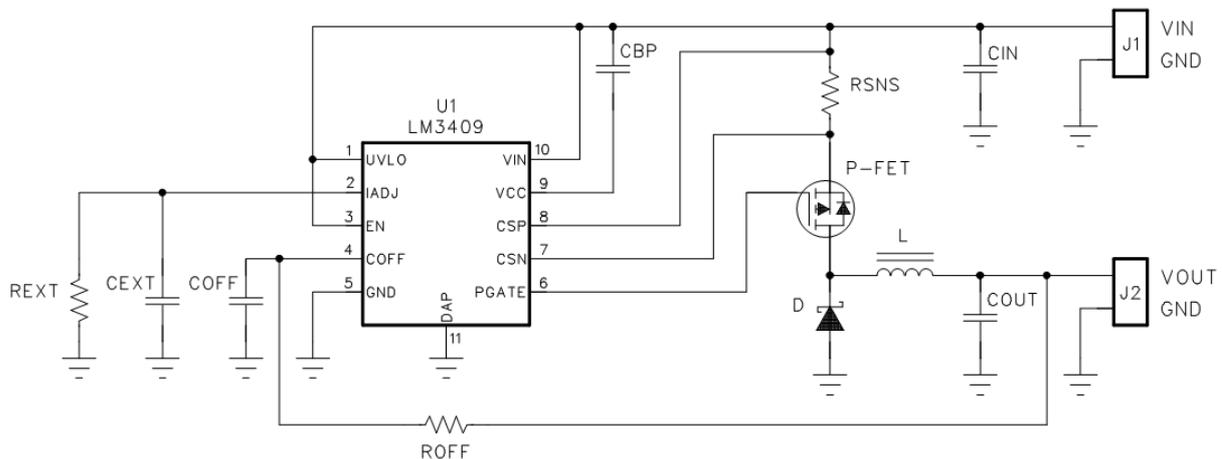


Figure 1 – Schematic for Constant Current Mode

To show the design process, a 12 V output should be limited to 1.0 A. In the following, the design procedure is explained. For a quick and easy design, an excel design sheet is available at TI.com found under the keyword PMP8531.

The converter switches only, when the output current is limited to 1.0 A. But in the worst case, this can happen a longer time. From a thermal perspective, the buck has to be designed that it can work in switching mode all the time. So the switching frequency which is set by the resistor R_{OFF} and the capacitor C_{OFF} needs to have a reasonable value. For this example, 400 kHz is a good value to keep the switching losses in a moderate range and to achieve a small inductance at the same time.

The inductance depends on the chosen current ripple. In normal applications, it is usually set to 20-30 %, but in this case 100 % can be selected. This means, the minimum current in the inductor is 0.5 A and the maximum current is 1.5 A. For the calculation in the excel sheet, an output voltage of 6.0 V is assumed, as the current ripple for a buck converter is maximum at 50 % duty cycle. Using these inputs for the calculation results in an inductance of 6.8 μ H.

Next step is choosing the sense resistor R_{SNS} which sets the maximum output current. The IC measures the voltage drop on the shunt by CSP (Pin 8) and CSN (Pin 7). The threshold is not fixed, it can be adjusted by three different variants using I_{ADJ} (Pin 2).

- Variant 1 - I_{ADJ} is left open
 I_{ADJ} has a $5\ \mu\text{A}$ current source which is clamped to $1.24\ \text{V}$ when the pin is left open. The threshold is always $1/5$ of the voltage set on I_{ADJ} which results in $248\ \text{mV}$.
- Variant 2 - External voltage applied to I_{ADJ}
An external voltage in the range of $0\text{-}1.24\ \text{V}$ can be applied to I_{ADJ} setting the threshold to $0\text{-}248\ \text{mV}$.
- Variant 3 - External resistor connected between I_{ADJ} and GND
The $5\ \mu\text{A}$ current source generates a voltage on the resistor. Again, the threshold is $1/5$ of it.

Variant 1 has the maximum threshold causing a voltage drop of $248\ \text{mV}$ which is already 2% of the $12.0\ \text{V}$ output voltage in this example. Variant 2 needs an additional precise voltage, which is usually not available. The right choice for this application is variant 3 due to its high flexibility. With the external resistor, the threshold can be set easily to a value which enables the designer to use a standard resistor value. At the same time, the threshold can be set very low to minimize the losses on the shunt. A threshold of $75\ \text{mV}$ is set by placing a $75.0\ \text{k}\Omega$ resistor between R_{EXT} and GND. For this example, a $50\ \text{m}\Omega$ sense resistor is needed causing a voltage drop of only $0.625\ \%$ of the $12.0\ \text{V}$ output voltage at the maximum current of $1.0\ \text{A}$.

Also the P-FET causes a voltage drop as it is always in line to the output. The overall voltage drop has to be calculated and considered. Usually a drop around $1\ \%$ is no problem for most applications. On the example circuit, the overall voltage drop at $100\ \%$ duty cycle is $177\ \text{mV}$ which equals less than $1.5\ \%$ at $1.0\ \text{A}$ load.

If this circuit is placed directly after another converter, no or only little additional input capacitance is needed as it uses the output capacitors of the converter in front of it.

The output capacitance depends of the voltage ripple which is allowed on the output when the converter switches. For proper functionality, a $1\ \mu\text{F}$ ceramic capacitor is enough in this application.

Figure 2 shows how the output current is regulated. The blue curve is the current in the inductor and below in red, the output current to the load.

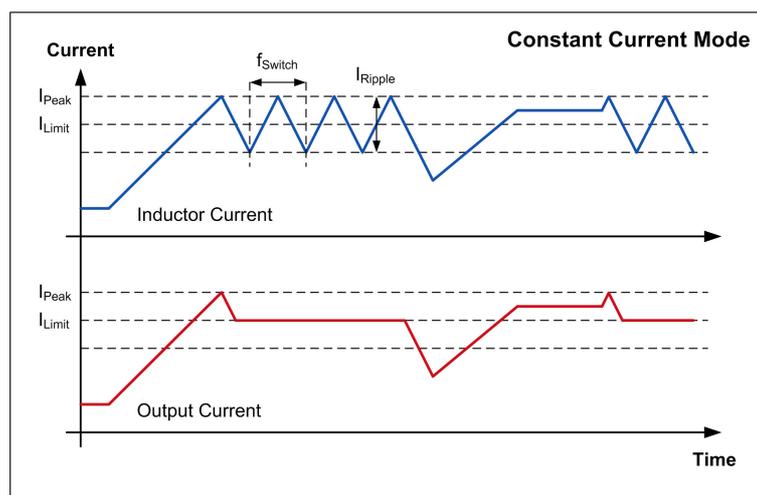


Figure 2 – Constant Current Mode Regulation Scheme

One very important thing to know is that the converter starts only switching if the peak current is achieved. I_{Limit} is the maximum output current ($1.0\ \text{A}$), I_{Peak} is the current limit plus one half of the current ripple ($0.5\ \text{A}$ at $100\ \%$ ripple). Choosing a lower ripple reduces the value of I_{Peak} which results in an earlier tripping.

Hitting the peak current of 1.5 A starts switching of the converter. Then the average output current is limited to 1.0 A as it can be seen on the red curve. The inductor current looks like on a normal buck converter.

As soon as the load current goes below 1.0 A, the converter stops switching and turns on the FET continuously (100 % duty cycle). If for example the load current stays at 1.25 A and thus below the peak current, it is not yet limited. This has to be kept in mind when designing a system.

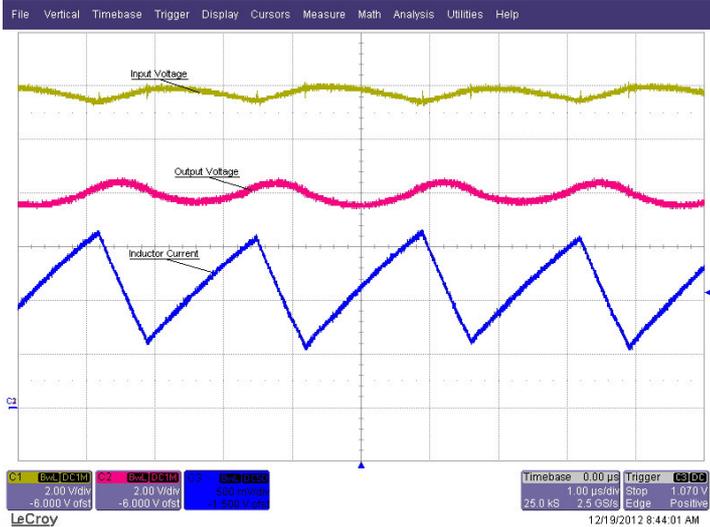


Figure 3 – 1.0A at 8.0V

Figure 3 shows on channel 3 (blue) the inductor current when the load current is limited to 1.0 A. The output voltage (channel 2, red) dropped already down to 8.0V, while the input voltage stays at 12.0 V. It shows a considerable voltage ripple, which is caused by the low output capacitance of only 1 μ F. To reduce it, just more capacitance has to be added.

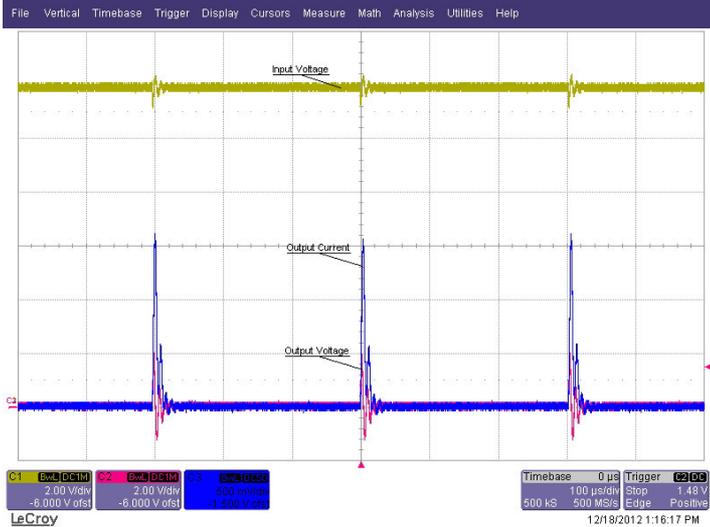


Figure 4 – Output shorted

If the output is shorted, the FET is switched off when the current hits the peak of 1.5 A. Due to the shorted output, the output voltage can not rise and therefore the converter is switched off for 300 μ s to protect the circuit until it starts again with a single cycle.

Comparator Mode

Using the IC in comparator mode is even less complicated and saves some parts. The functionality is pretty simple. Unlike before, the FET is switched off and disconnects the load from the source immediately if the adjusted current limit is reached. After a delay of $300\ \mu\text{s}$ the FET is switched on again. It does work as a current source like in the configuration shown previously.

Figure 5 shows the schematic for comparator mode, which is reduced for a significant amount of parts (input and output capacitors, inductor, diode).

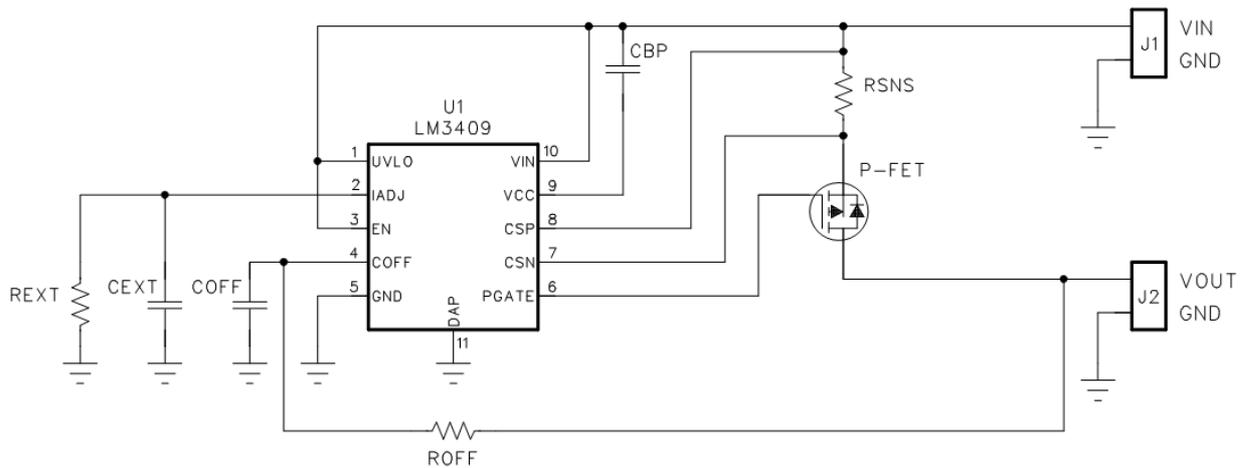


Figure 5 - Schematic for Comparator Mode

Choosing a sense resistor R_{SNS} and setting the current limit threshold by I_{ADJ} works like described in the previous section. This configuration is also supported by the excel design sheet and makes designs easy.

Figure 6 shows the functionality of the circuit, which is practically an electronic fuse.

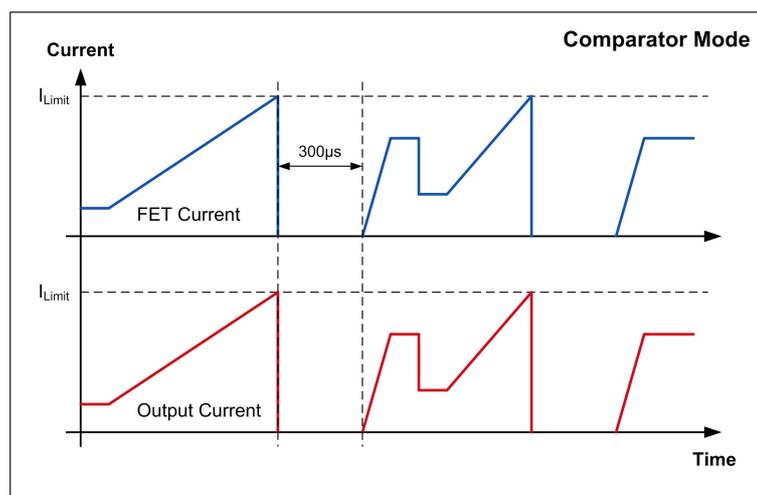


Figure 6 - Comparator Mode Regulation Scheme

The FET is switched on continuously without switching as long as the load current is below the limit. If the limit is exceeded, the FET disconnects the load from the source for $300\ \mu\text{s}$ until it is reconnected.

Conclusion

This article shows that an IC which is generally designed and used for LED drivers can be used as a current limiter for various applications. Its functionality and behavior fulfills all needs and depending on the external circuitry, two different modes are possible. In constant current mode, it acts like a current source, in comparator mode like an electronic fuse.

Compared to other solutions which are mainly based on transistors acting as linear regulators, this solution has only low losses in constant current mode due to its switch mode power supply topology. Due to the low adjustable current sense threshold, the losses on the shunt can also be very low.

The total solution size for constant current mode with a complete buck power stage can be small as 0.4 x 0.8 inch (10 x 20 mm). In comparator mode, fewer parts are needed and the board space is even less.

An excel design sheet is available can be found under the keyword PMP8531 on TI.com. It reduces design time and enables the user to get quickly a working solution.

About the author

Matthias Ulmann was born in Ulm, Germany, in 1980. He was awarded a degree in electrical engineering from the University of Ulm in 2006. After working for several years in the field of motor control and solar inverters (specialized in IGBT-drivers), he joined TI's Analog Academy for a one year trainee program. Since 2010 he has worked in the EMEA Design Services Group as a Reference Design Engineer in Freising, Germany. His design activity includes isolated and non-isolated DC/DC converters for all application segments.

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