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Precision Output Current Limiting Using Average Current Monitor Feature

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Introduction

Traditionally, current limiting of a buck regulator is accomplished by monitoring the switch current. This method protects the switch effectively, but the maximum output current limit will vary widely. In some emerging applications such as battery/super-capacitor chargers, USB power supplies, or LED drivers, very tight control of the maximum output current is now mandatory. Achieving higher accuracy of current limit/regulation is a competitive advantage.

In this article, a unique average output current monitor feature of National Semiconductor's LM5117 synchronous buck controller will be introduced and a method to use this feature in order to implement precise current limiting will be shown. An example of a constant current regulator providing output over-voltage protection will also be presented.

Output Current Limit Variation When Using Peak Current Limit

Shown in ***Figure 1*** is a block diagram of a current mode -controlled buck regulator implementing traditional cycle-by-cycle peak current limiting. This popular current limiting scheme senses the current through the MOSFET during the on-time. The current can be sensed using the MOSFET's 'on' resistance, inductor resistance, a dedicated sense resistor, or a Sense FET.

The current limit comparator turns off the MOSFET if the sensed current (and the addition of slope compensation) exceeds the current limit threshold. Once the MOSFET is turned off, the inductor current will decay during the balance of the clock period to a valley level. The MOSFET will be turned on again at the start of the next clock period and if the overload condition still exists, the current will rise again to the peak limiting level.

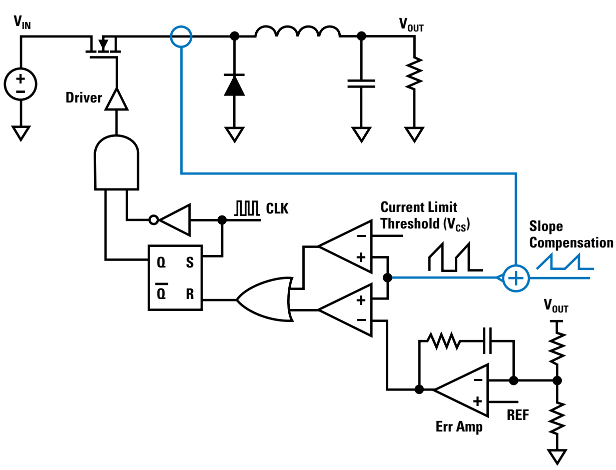

Figure 1. Traditional Cycle-by-Cycle Peak Current Limiting

In applications where the input voltage is relatively large in comparison to the output voltage, controlling narrow pulse widths and short duty cycles are necessary for regulation. However, traditional peak current-mode control needs a blanking time which blanks large leading edge spikes during turn-on of the high-

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side switch. Controlling narrow pulse widths will be limited by this blanking time. Emulated peak current-mode control is free of this limit and allows control of narrow pulse widths because the inductor current information is sensed—across the low-side switch or a low-side sense resistor—during off-time. *Figure 2* shows a simplified block diagram of a buck regulator implementing emulated peak current mode control with peak cycle-by-cycle current limiting.

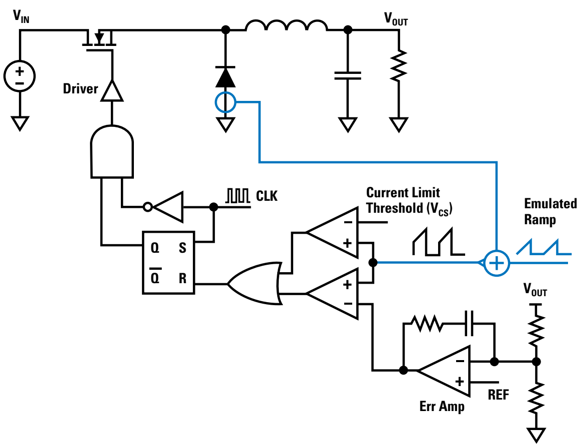
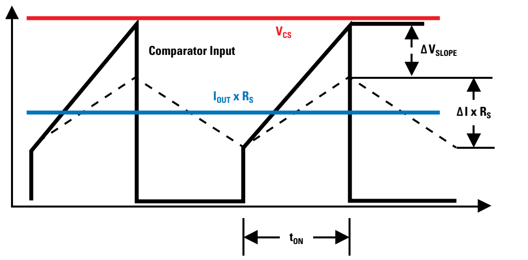
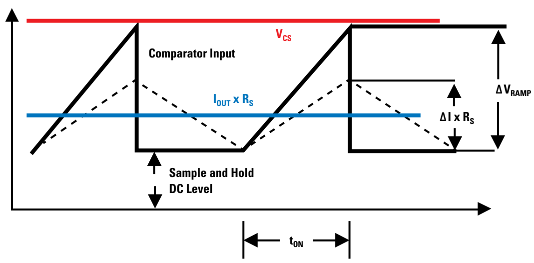


Figure 2. Emulated Peak Current Limit



(a) Traditional Peak Current Limit



(b) Emulated Peak Current Limit

Figure 3. Current Limit Comparator Input

The LM5117 emulated current-mode controller does not actually measure the MOSFET switch current but rather reconstructs the signal as shown in *Figure 3(b)*. The MOSFET switch current waveform can be broken down into two parts, a base or pedestal and a ramp. The pedestal represents the minimum inductor current value (or valley) over the switching cycle. The inductor current is at its minimum the instant the free-wheel diode turns off, as the buck switch turns on. The buck switch and the diode have the same minimum current value, occurring at the valley of the inductor current. A sample and hold measurement of the free-wheel diode current, sampled just prior to the turn-on of the buck switch, can be used to capture the pedestal level information. A ramp signal which emulates the positive slope of the inductor current is added to the sample-and-hold DC level.

While both traditional and emulated current mode control protect the MOSFET switch effectively, the maximum output current will vary widely when operating with varying input and output voltages. The relationship between input/output voltage and the maximum output current can be calculated as follows:

$$I_{OUT(MAX)} = \frac{V_{CS}}{R_S} - \frac{\Delta I}{2} - \frac{\Delta V_{SLOPE}}{R_S}$$

Traditional Peak Current Limit

$$I_{OUT(MAX)} = \frac{V_{CS}}{R_S} + \frac{\Delta I}{2} - \frac{\Delta V_{RAMP}}{R_S}$$

Emulated Peak Current Limit

Where V_{CS} is the current limit threshold, R_S is the resistance of the sensing resistor, ΔV_{RAMP} is the amount of emulated ramp, ΔV_{SLOPE} is the amount of slope compensation, and ΔI is a peak-to-peak inductor current ripple, defined as:

$$\Delta I = \frac{V_{OUT}}{V_{IN} \times F_{SW}} \times \frac{(V_{IN} - V_{OUT})}{L_{OUT}}$$

The relationship between the maximum output current and the input voltage in emulated peak current limit is illustrated in *Figure 4*, with output voltage of 5V.

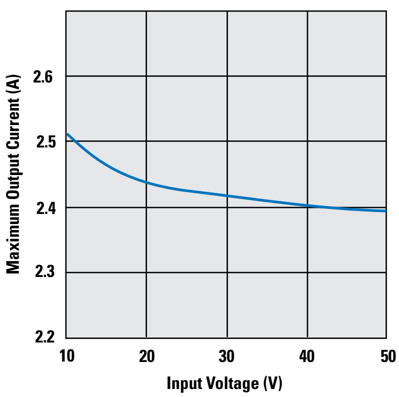


Figure 4. Maximum Output Current vs Input Voltage

The relationship between the maximum output current and the output voltage using emulated peak current limit is shown in *Figure 5*, with input voltage of 48V.

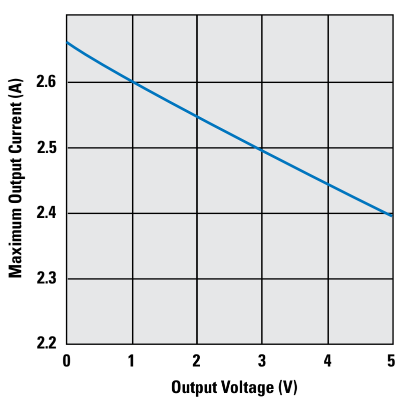


Figure 5. Maximum Output Current vs Output Voltage

Average Output Current Monitor Feature

In steady-state, the output current of the buck regulator is equal to the average of inductor current. A unique feature of the LM5117 is an analog telemetry feature that averages the inductor current and provides a voltage proportional to the output (inductor) current. The current monitor signal is updated every clock cycle.

Figure 6 illustrates the LM5117 current monitor. A current amplifier samples the voltage across the sense resistor with a gain of 10 to form the pedestal for the emulated ramp. The conditioner averages the amplified current sense signal. Finally, a buffer amplifier with a gain of 2 is used to buffer and minimize loading effects.

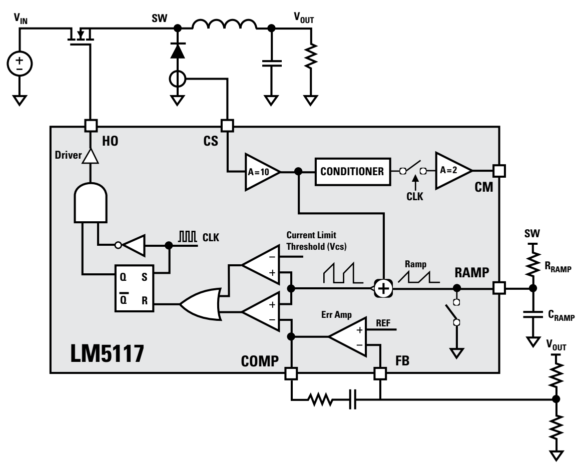


Figure 6. Block Diagram of Current Monitor and Ramp Generator

The output of the buffer amplifier is updated every clock cycle as shown in *Figure 7*. The current monitor can be used as an input to an A to D converter to digitally monitor the output current or calculate power in order to check system performance. The current monitor can also be used as an accurate current feedback for precise output current limiting.

Precision Output Current Limiting Using Average Current Monitor Feature

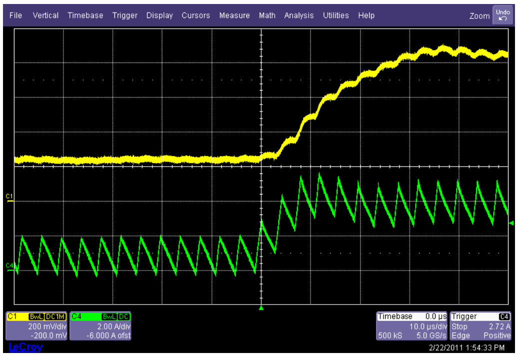


Figure 7. Current Monitor Output—Upper: CM output, measured through 5 kΩ and 1 nF RC filter; Lower: Inductor Current

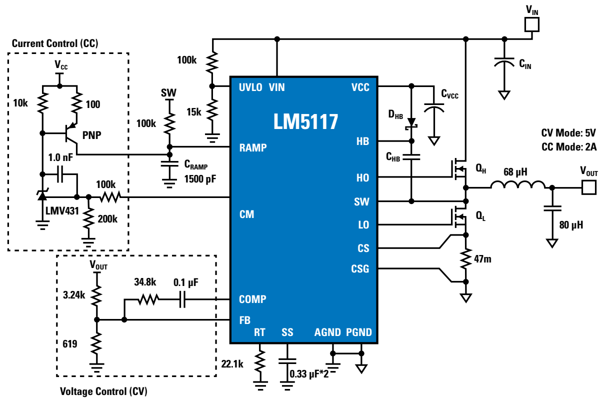


Figure 8. Constant Voltage Regulator with Precision Current Limit

Constant Voltage Regulator with Precision Current Limit

In applications such as battery/super-capacitor chargers, both accurate voltage and current regulation are required. The LM5117 can be configured as a constant voltage with precision current limit as shown in *Figure 8*. In this configuration, there is much less variation in the output current limiting when compared to the traditional cycle-by-cycle peak current limiting. The LMV431 shunt regulator and the PNP transistor configure a voltage-to-current amplifier in a closed current loop. This amplifier circuitry does not affect the normal operation when the output current is less than the set-point. When the output current rises to the set-point, the PNP transistor starts to source current into C_{RAMP}. The PNP current increases the positive slope of emulated ramp, providing a feedback path into the controller to limit the maximum output current.

As a result, the output can be connected directly to a battery and be charged as a constant current source when the battery voltage is less than the output voltage set-point. Once the battery potential reaches the output voltage set-point, the controller will smoothly transition to voltage regulation mode, as shown in *Figure 9*. The V_{OUT} vs. I_{OUT} curves shown in *Figure 10* illustrate the accuracy of the current limit circuit shown in *Figure 8*.

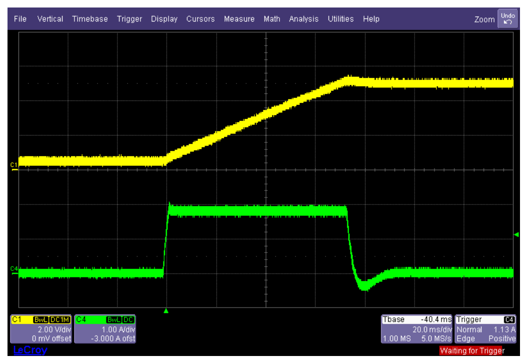


Figure 9. CC and CV Regulation Waveforms (Upper : Output Voltage, Lower: Output Current)

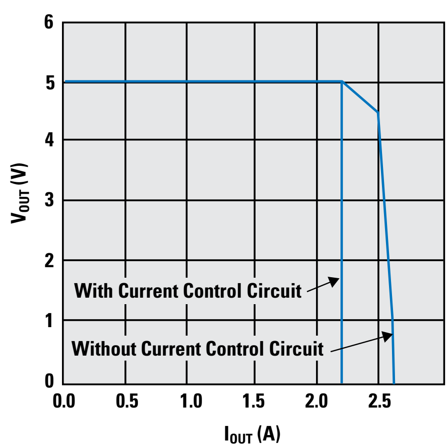


Figure 10. Output Voltage vs Output Current

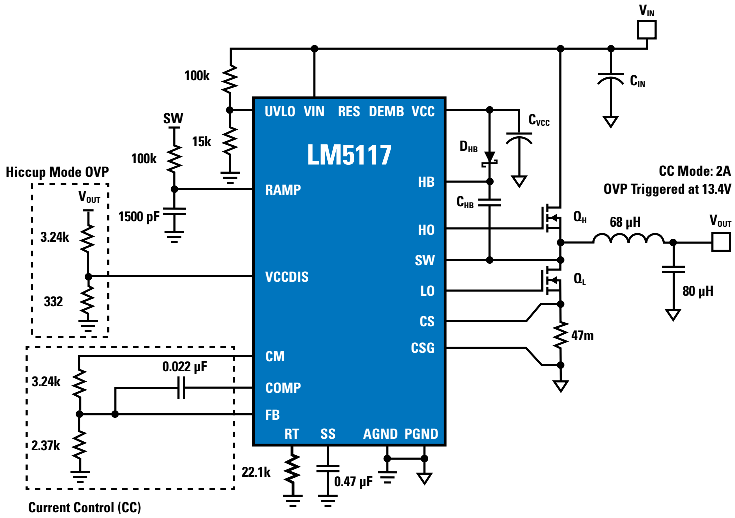


Figure 11. Constant Current Regulator with Hiccup-Mode Over-Voltage Protection

Constant Current Regulator with Hiccup-Mode Over-Voltage Protection

In applications such as LED drivers, a constant current output is required, while output over-voltage protection is required as a protection function. The LM5117 can also be configured as a constant current regulator by using the current monitor feature (CM) as the feedback (FB) input as shown in *Figure 11*. A voltage divider at the VCCDIS pin from V_{OUT} to AGND can be used to protect against output over-voltage, if required. When the VCCDIS pin voltage is greater than the VCCDIS threshold, the controller disables the VCC regulator and the VCC pin voltage decays. When the VCC pin voltage is less than the VCC UVLO threshold, both HO and LO outputs stop switching. Due to the time delay required for VCC to decay below the VCC UVLO threshold, the over-voltage protection operates in hiccup-mode.

Conclusion

While traditional cycle-by-cycle peak current limiting protects the MOSFET effectively, maximum output current varies widely with changes in input and output voltage. In applications requiring tight regulation of output current, using the LM5117 current monitor feature as feedback allows easy configuration of a constant current regulator or precision current limiting. The current monitor feature can also enable various value-added features by providing the average output current monitoring information to the system.

Additional Resources

LM5117 Datasheet
LM5117 Evaluation Board

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