Application Report

SNVA829–June 2018

How to Design a Simple Constant Current/Constant Voltage Buck Converter

ABSTRACT

Technical Information about designing a constant current, constant voltage (CC/CV) power converter is limited. The design implementation can be challenging from a complexity, efficiency, and cost perspective. The LM5117 device with its current monitor (CM) pin greatly simplifies the design process, allows current regulation without using a lossy current sense resistor, and saves cost in the process. This application note details the design approach using the LM5117 CM pin and the LMV431 for current regulation and voltage regulation, respectively.

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1 Introduction

A DC-to-DC converter is typically implemented as a constant voltage (CV) regulator. The control loop adjusts the duty cycle in order to maintain a constant output voltage regardless of changes to the input voltage and load current.

A constant current (CC) converter regulates current the same way: the control loop adjusts the duty cycle to maintain a constant output current regardless of changes to the input voltage and output resistance. A change in output resistance causes the output voltage to adjust as the load resistance varies; the higher the output resistance, the greater the output voltage.

A CC/CV converter regulates both current and voltage depending on the output resistance level.

2 Application Examples

Many applications limit the maximum output resistance and resulting output voltage so that components connected to the output won't be damaged, which is where constant voltage regulation engages. Some examples of CC/CV converter uses are applications driving a light-emitting diode (LED) or charging batteries or supercapacitors. The current is regulated for a range of output resistances; should the resistance increase beyond a certain level, the voltage is regulated, or "clamped."

Output-voltage accuracy may be crucial, particularly in battery applications and supercapacitor chargers. Precise voltage regulation enables more energy storage because you can set the voltage regulation point as close as possible to the maximum safe operating voltage rating of the storage device.

3 Traditional Methods of Implementing CC/CV

Figure 1 outlines a typical discrete implementation of a CC/CV converter. The converter requires a sense resistor (R_{SENSE}), an amplifier and a voltage regulation circuit (Vz). The current flowing through R_{SENSE} sets the voltage across R_{FB}, which is the feedback voltage of a controller. In this way, the current is regulated. As R_{OUT} increases, the voltage on the output rises to a point where the Zener diode conducts, and the device transitions from a CC converter to a CV converter.

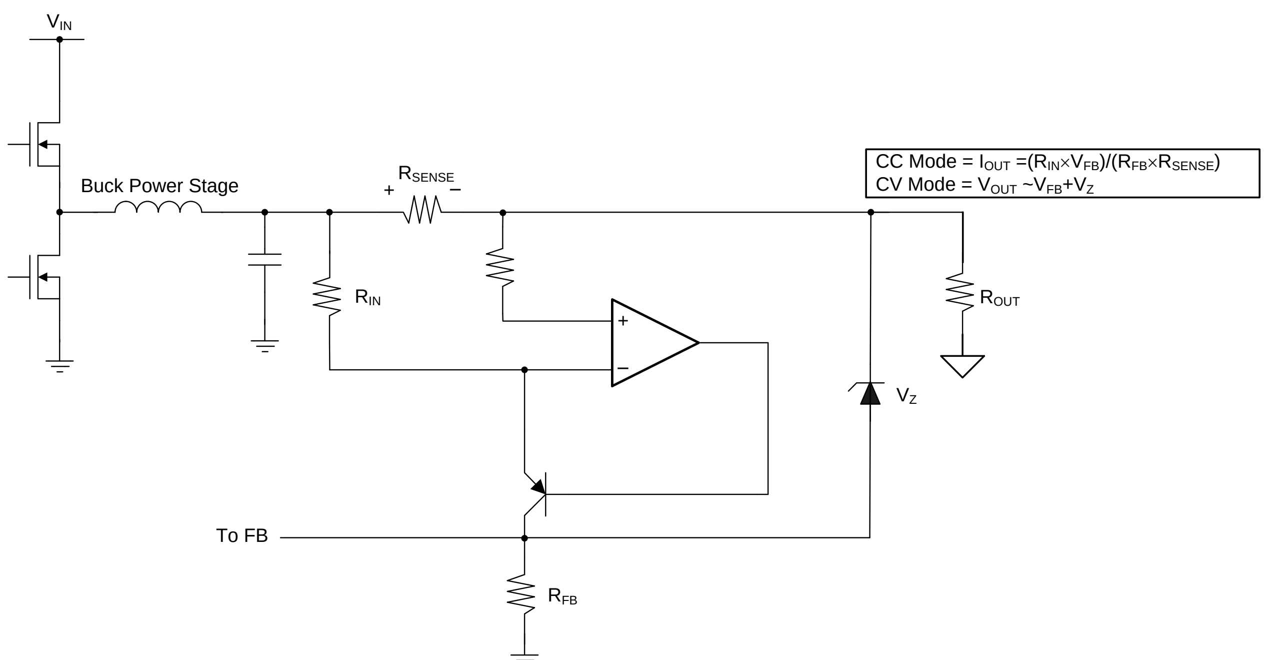

Figure 1. CC/CV Implementation With a Buck Topology

As previously mentioned, the current through R_{SENSE} sets the feedback voltage, which regulates the output current. Equation 1 expresses the relationship between the output current and V_{FB}:

$$I_{OUT} = \frac{R_{IN} \times V_{FB}}{R_{FB} \times R_{SENSE}} \quad (1)$$

Assuming a resistive load, Equation 2 governs the voltage at the output:

$$V_{OUT} = I_{OUT} \times R_{OUT} \quad (2)$$

Equation 3 sets the voltage regulation level:

$$V_{CLAMP} = V_{REF} + V_Z \quad (3)$$

As seen in Figure 1, a Zener diode regulates the voltage in CV mode. Using a Zener as a voltage clamp yields relatively poor voltage-accuracy performance because of the variation in Zener voltages from device to device. Two Zener diodes are sometimes used in series to prevent leakage current flowing from cathode to anode, which if present causes errors in the current regulation loop.

4 Drawbacks of the Traditional Method

The traditional method requires the use of a sense resistor in series with the output in order to sense current. As a result, resistive losses will impact efficiency; Equation 4 shows the losses in the sense resistor

$$R_{SENSE_{loss}} = I_{OUT}^2 \times R_{SENSE} \quad (4)$$

Higher losses increase the operating temperature and reduce system efficiency because the resistor has all of the output current flowing through it. Cost also increases because low milliohm current-sense resistors are relatively expensive compared to a small signal resistor. The common-mode voltage range of the amplifier needs to be rated to the maximum output voltage. A high output voltage might increase the cost of the amplifier. To help save costs, you could use a floating bias supply to reduce the common-mode voltage range requirement, but that will increase the component count. The solution presented in Figure 1 has many disadvantages, including added design complexity, board real estate required, cost and impact on system efficiency.

5 A Simple CC/CV Method Using the LM5117 Device

The LM5117 is an emulated peak current-mode synchronous buck controller suitable for high-current, wide step-down conversions. The major benefit of using the LM5117 in a CC/CV application is that it has a current monitor (CM) feature. The CM pin provides an accurate voltage that is proportional to the output current of the buck power stage. The designer can use the CM pin as the current loop feedback, saving the additional current-sense circuitry that the traditional method requires. The voltage present on the CM pin is accurate to ±2%, provided that the converter is set to forced pulsed width modulation (FPWM) or is in continuous conduction mode. Figure 2 shows a basic CC/CV regulator implementation using the LM5117.

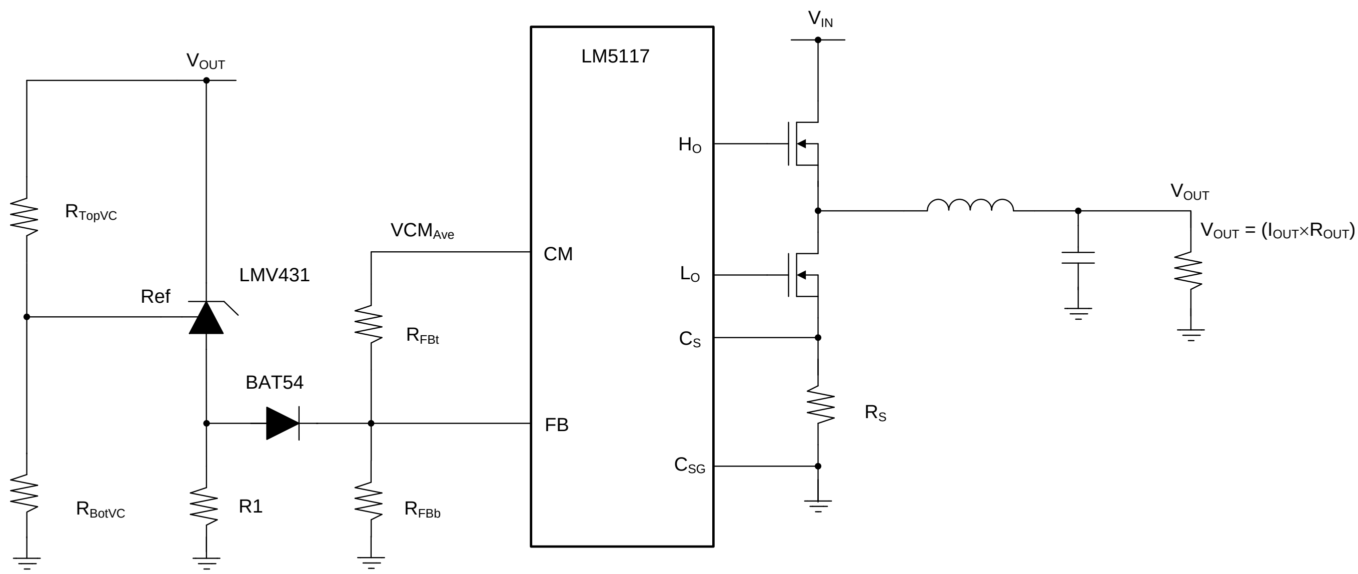

Figure 2. CLM5117 CC/CV Basic Implementation

6 CC Programming

Equation 5 describes the relationship between the CM voltage and I_{OUT}:

$$VCM_{Ave} = (I_{PEAK} + I_{VALLEY}) \times R_S \times A_S \tag{5}$$

Equation 6 simplifies Equation 5:

$$VCM_{Ave} = 2 \times I_{OUT} \times R_S \times A_S \tag{6}$$

As can be seen, the CM pin enables the designer to omit the series power dissipative current-sense resistor at the output. R_S is the current-sense resistor of the power stage used to generate a ramp for the current-mode pulse-width modulation (PWM) loop. A_S is the current-sense amplifier gain of the LM5117, which has a typical value of A_S = 10.

For example, assume that I_{OUT} = 10 A and R_S = 10 mΩ. Using Equation 7:

$$VCM_{Ave} = 2 \times 10\ \text{A} \times 0.01\Omega \times 10$$

$$VCM_{Ave} = 2\ \text{V} \tag{7}$$

Setting the resistor divider network from the CM pin to ground and connecting the divider node to the feedback pin sets the current regulation point. With 2 V at the CM pin, selecting the proper resistor-divider ratio sets the current regulation level. To set the resistor-divider values for 10-A current regulation, select RFBb = 10kΩ and calculate RFBt using Equation 8:

$$R_{FBt} = \left(\frac{VCM_{Ave}}{V_{FB}} - 1 \right) R_{FBb} \tag{8}$$

which yields an R_{FBt} value of 15 kΩ.

Remember to account for the reduction in A_S caused by placing series filter resistors from R_S and ground to C_S and C_{SG}, respectively. Refer to the LM5117 data sheet for more details on how resistors in series with the current-sense pins affect the gain of the internal current-sense amplifier.

7 CV Programming

CV programing is achieved by using an LMV431 as a voltage clamp. Assume a voltage clamp level of 12 V. The forward voltage drop Vfwd across BAT54 is 0.5 V, and the FB voltage of the LM5117 is 0.8 V. The voltage clamp engages when the voltage across R1 is equal to the voltage calculated using Equation 9:

$$V_{R1} = V_{FB} + V_{FWD} \tag{9}$$

Therefore, V_{R1} = 1.3 V.

The voltage at the reference pin of the LMV431 must be a reference voltage above V_{R1}. The LMV431 has a reference voltage of 1.24 V, so the voltage at the reference pin of the LMV431 is equal to the voltage calculated using Equation 10:

$$V_{REF} = V_{R1} + V_{REF_{LMV431}} \tag{10}$$

Therefore, a V_{REF} = 2.54 V is required for the LMV431 to conduct current from its cathode to anode.

Select R_{BotVC} = 10 kΩ and calculate R_{TopVC} using Equation 11:

$$R_{TopVC} = \left(\frac{V_{CLAMP}}{V_{REF}} - 1\right)R_{BotVC}$$

$$R_{TopVC} = 37\ k\Omega \tag{11}$$

8 Power Design of the LM5117

The design approach for the power section of a CC/CV converter using the LM5117 is the same as it is for a basic buck converter. TI suggests carrying out the design at the highest output power level (which is the highest output resistance) using either WEBENCH® Designer or the LM5117 Quick Start Calculator. Refer as well to the LM5117 data sheet for guidance on the design of the buck power stage.

9 Example Schematic

Figure 3 shows a 30 V-to-54 V input, 27 V-at-6 A output CC/CV implementation using the LM5117.

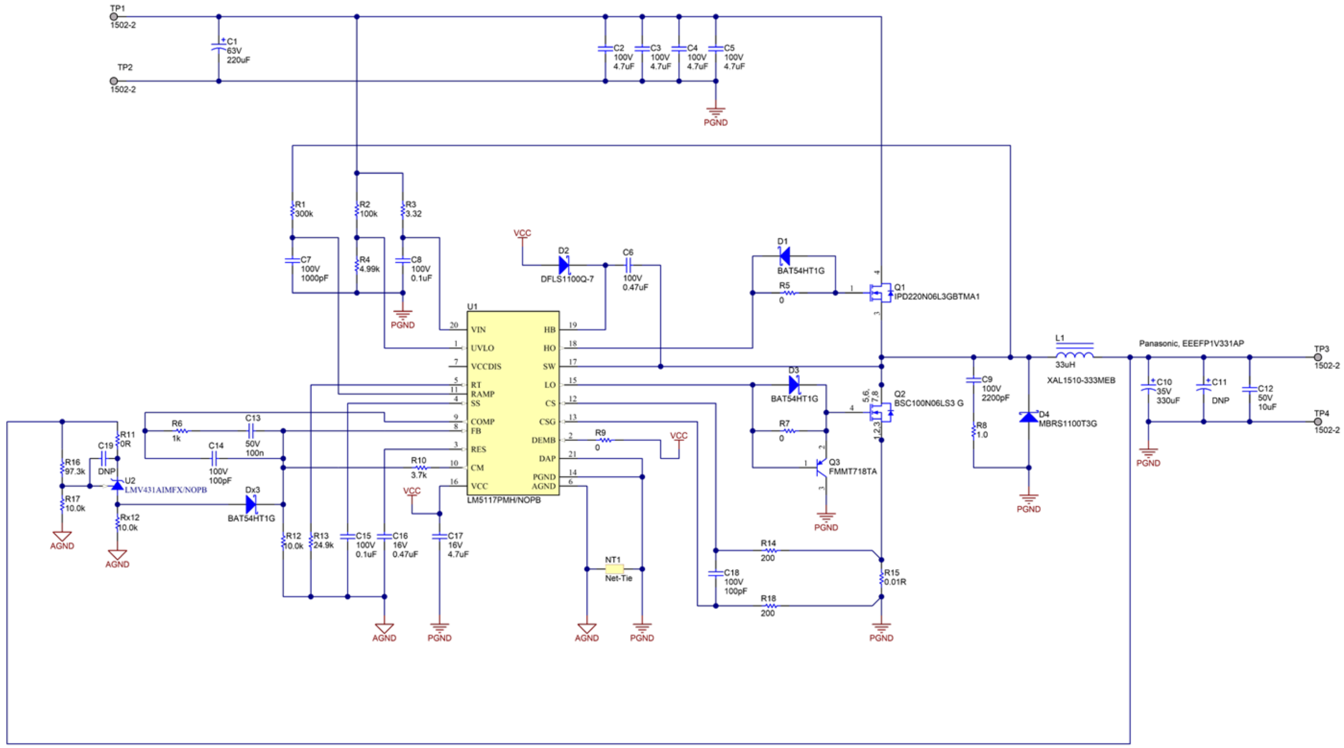

Figure 3. A 30 V-to-54 V Input, 27 V-at-6 A Output CC/CV Converter Using the LM5117

10 Results

Figure 4 shows the efficiency results with increasing output resistance.

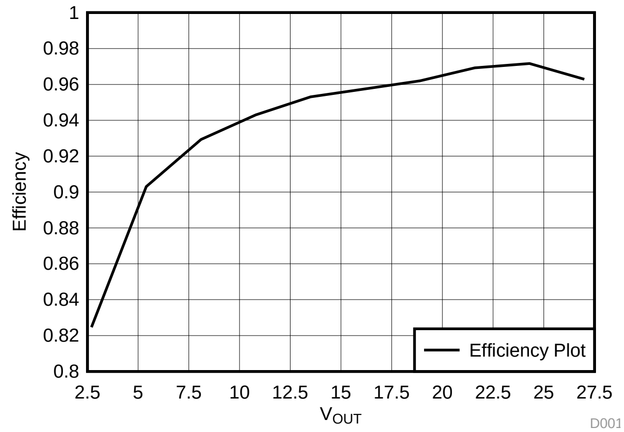

Figure 4. Efficiency at 30 V_{IN}

Figure 5 shows load regulation and the voltage setpoint with increasing output resistance.

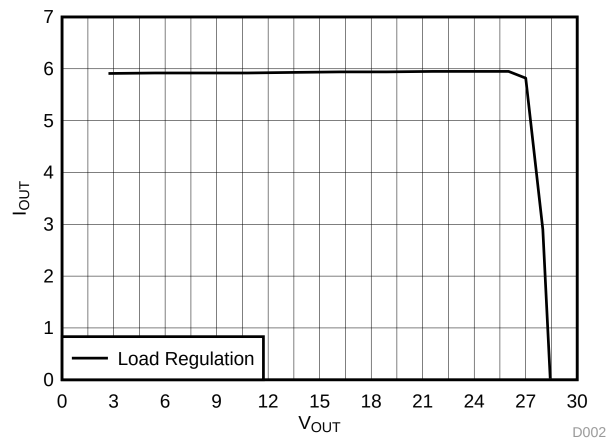

Figure 5. Load Regulation at 30 V_{IN} With Increasing R_{LOAD} (V_{OUT} / I_{OUT})

Figure 6 shows the switch node (CH3), V_{OUT} ripple (CH1) and output current (CH4) at 30 V_{IN}, 25 V_{OUT} at 6 A.

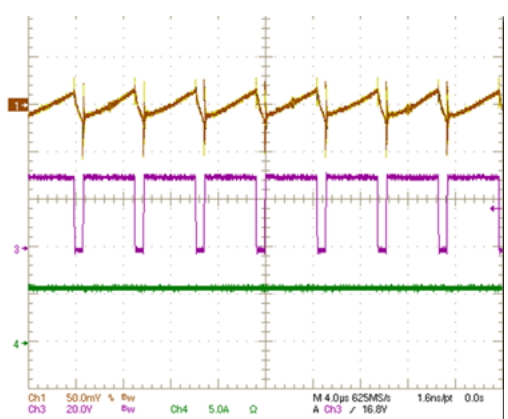

Figure 6. Steady-State Waveforms

Figure 7 shows the load-transient performance V_{OUT} (CH1) and output current (CH4) when stepping a constant resistive load from 60 Ω to 120 Ω.

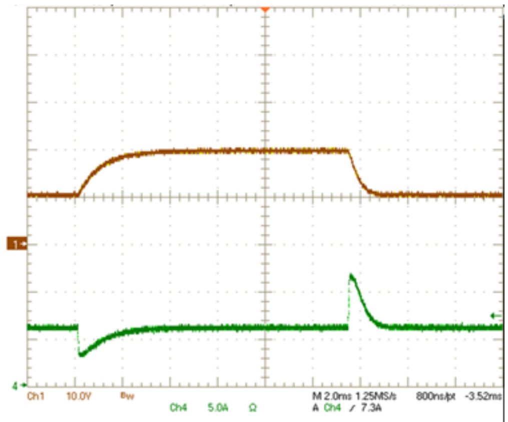

Figure 7. Load-Transient Performance

11 Summary

The LM5117 configured as a CC/CV converter provides accurate current regulation, while offering many advantages over the traditional implementation. The design approach is relatively simple, and enables significant reductions in size, cost, and power losses.