

# How to Implement a Simple Constant Current Regulation Scheme to a PCM Based Buck



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## ABSTRACT

A buck converter is usually implemented as a constant voltage (CV) regulator. When the input voltage and load current change, the control loop adjusts the duty cycle to keep the output voltage constant.

However, more recently, many applications require regulation of both the output current and the output voltage. This is often referred to as constant current, constant voltage regulation (CC/CV). Typically, to implement CC/CV regulation, the designer needs to modify a CV regulation scheme adding circuitry to the feedback loop. This application note shows how to convert a peak current-mode (PCM) control scheme, configured as a CV regulator into a CC/CV regulator. The suggested approach herein can be applied to a controller, converter or module. Test results are also provided to demonstrate feasibility.

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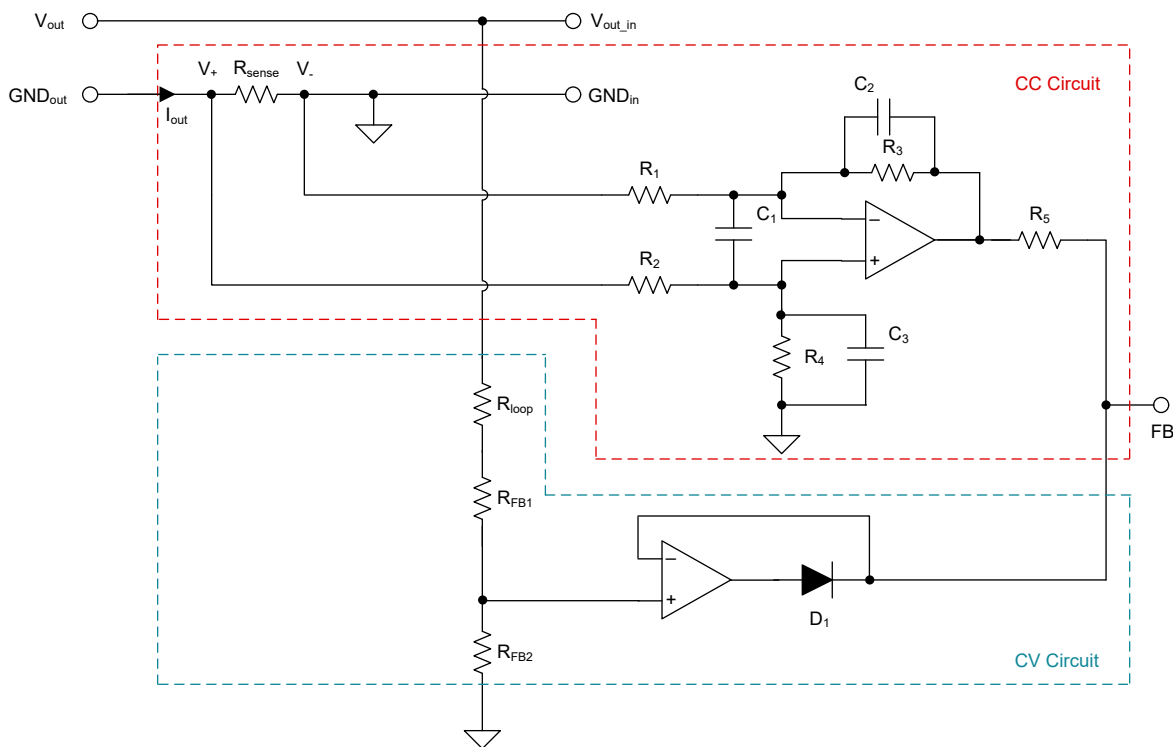
## 1 Introduction

Currently, there is a growing demand for CC/CV regulators in many applications, such as super capacitor energy backup, eBike GSM module and multi-cell battery stacks, USB power delivery, server BBU for 48 V bus architecture, and so on. However, buck regulators are typically implemented with CV regulation, therefore external circuitry is necessary to realize CC/CV regulation.

This application note provides a simple CC/CV configuration that can be added to most buck regulator products with PCM control, including controllers, converters and modules. Design principles and design considerations are discussed and test results are provided to show design implementation feasibility.

## 2 General Simple CC/CV Configuration Circuit

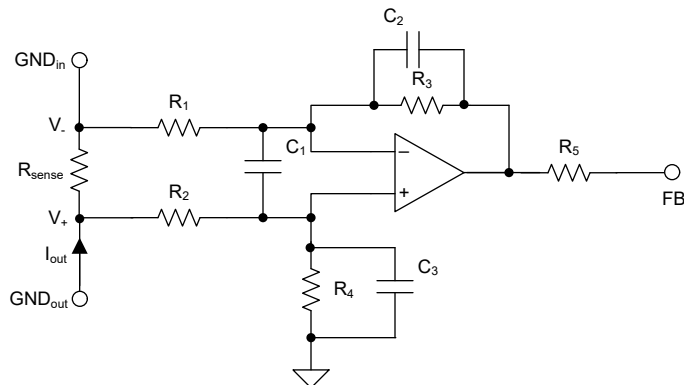
Typically, the output voltage of buck can be set using external resistive dividers from the output to the relevant FB pin, which achieves CV regulation. In order to achieve CC regulation, a current sensing circuitry needs to be added to the feedback loop. This circuitry provides a voltage signal to the FB pin, that is proportional to the output current. However, it is necessary to add an additional follower circuit to the voltage feedback loop in order to prevent both CC/CV regulation schemes working at the same time. Adding the follower circuit to the CV feedback loop ensures that only CC or CV regulation is in control at any given time. The feedback loop with the higher voltage, present at the FB pin determines which one of the two regulation schemes, is in control. [Figure 2-1](#) shows a common CC/CV scheme.



**Figure 2-1. CC/CV Configuration Circuit**

### 2.1 CC Circuit Design

As can be seen in [Figure 2-2](#), the CC regulation scheme is composed of a current sense resistor and a differential amplifier. As the output current flows through the current sense resistor it generates a differential voltage which is amplified and level shifted to a voltage referenced to ground. The voltage referenced to ground is proportional to the output current flowing through the current sense resistor. When the loop is in regulation, the FB pin voltage is equal to the internal reference of the regulator.



**Figure 2-2. External CC Circuit**

Equation 1 shows the relationship between the voltage sensed across the current sense resistor, the output current and the gain of the differential amplifier.

$$V_{FB} = K \times I_{out} \times R_{sense} \quad (1)$$

$I_{out}$  is the output current,  $R_{sense}$  is the current sense resistance and  $K$  is the gain of the differential amplifier.

Equation 2 is holds true when  $R_1 = R_2$ ,  $R_3 = R_4$ .

$$K = \frac{R_3}{R_1} \quad (2)$$

For most converters with PCM control, when in regulation, the FB pin voltage is equal to its internal reference of the error amplifier ( $V_{ref}$ ). Note that the reference voltage can vary between products. For example, the  $V_{ref}$  of TPSM63610 and the LM5149 is 1V and 0.8V respectively.

$$V_{FB} = V_{ref} \quad (3)$$

Combining Equation 1, Equation 2 and Equation 3 which consists of the gain of the differential amplifier, the current sense resistor value and the reference of the regulator in use, the output current can be set to the desired level. Equation 4 calculates the power loss in the selected current sense resistor.

$$P_{sense} = I_{out}^2 \times R_{sense} \quad (4)$$

Higher losses not only increase the operating temperature but also reduce system efficiency, because all of the output current will flow through  $R_{sense}$ . Generally speaking, consider the current sense resistor package size and power losses, the resistance cannot be too high. A current sense resistor value of 10 mΩ was selected and the results of the the experiments are published in this application note. The values of capacitors  $C_2$  and  $C_3$  in the differential amplifier circuit are related to the CC circuit loop. Since both the CC and CV circuits are added to the FB pin, to stabilize the loop, it is necessary to slow down the CC loop as much as possible. We recommend that the values of  $C_2$  and  $C_3$  be between 1 nF and 10 nF.

For example, assume that  $I_{out} = 8$  A and  $R_{sense} = 10$  mΩ. When we use this circuit on TPSM63610EVM or LM61495EVM, because the  $V_{ref} = 1$  V, using Equation 1 through Equation 3, we can get that with  $R_1 = R_2 = 1$  kΩ,  $R_3 = R_4 = 12.5$  kΩ.

The operational amplifiers in the CC and CV circuits can be powered by an external LDO, and the power supply voltage is 5 V. But in practical applications, if the output voltage of the VCC pin of the chip is also 5 V, we can directly use the VCC pin to power the op amp. Note that the VCC pin has a current limit, so a 1 kΩ resistor ( $R_5$  in Figure 2-2) needs to be added to the output of the CC circuit to limit the current.

In addition, the above circuit uses low side current sensing, and the two ends of the  $R_{sense}$  are  $GND_{in}$  and  $GND_{out}$ . High side current sensing can also be used, and the two ends of the  $R_{sense}$  are  $V_{out\_in}$  and  $V_{out}$ . In this way, it is necessary to choose the appropriate op amp according to the output voltage, mainly considering the power supply range of the op amp and the common mode (CM) voltage range.

## 2.2 CV Circuit Design

The CV circuit shown in Figure 2-3 is mainly composed of the upper and lower feedback resistors (designated as  $R_{FB1}$  and  $R_{FB2}$ , respectively), a follower and a diode. The circuit adjusts the output voltage by adjusting the resistance value of  $R_{FB1}$  and  $R_{FB2}$  by Equation 5.

$$R_{FB1} = \left( \frac{V_{out}}{V_{ref}} - 1 \right) \times R_{FB2} \quad (5)$$

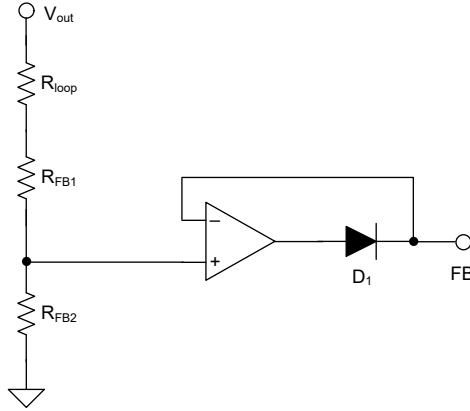


Figure 2-3. External CV Circuit

For example, assume that  $V_{out} = 5\text{ V}$ . When we use this circuit on TPSM63610EVM or LM61495EVM, according to Equation 5, we can get  $R_{FB1} = 100\text{ k}\Omega$ ,  $R_{FB2} = 24.9\text{ k}\Omega$ .

For the selection of the resistance values of  $R_{FB1}$  and  $R_{FB2}$ , please refer to the data sheet of the buck products. In addition, the resistor  $R_{loop}$  in Figure 2-3 is used for frequency response measurements, and a typical value of  $49.9\ \Omega$  is used. Diode  $D_1$  is mainly used to make sure that only one loop (current loop or voltage loop) is working at a time. In this application note, the voltage loop is the main loop, and the current loop is the secondary loop. Generally speaking, the current loop can be slowed down as much as possible to avoid interference with the voltage loop. Finally, the negative feedback look of the buffer is wrapped around diode  $D_1$  to ensure that the diodes voltage drop and temperature variations are nullified and will not effect the voltage set point accuracy.

## 3 Example Schematic

Figure 3-1 shows the schematic diagram of the external CC/CV circuit board. The parameters are designed for the TPSM63610EVM and LM61495EVM to realize the CC/CV function. The constant current is 8A and the constant voltage is 5 V. For 5 V power supply, we choose to use the VCC on the EVM board for power supply rather than from the LDO.

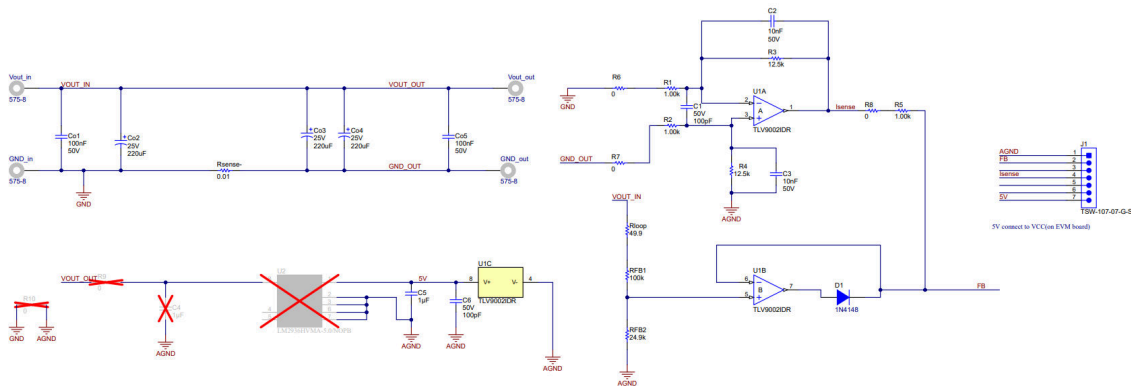


Figure 3-1. 5 V-8 A Output CC/CV Schematic Using with TPSM63610EVM or LM61495EVM

## 4 Test Results and Performance Curves

### 4.1 Test Method

Figure 4-1 shows the physical connection diagram of CC/CV board and TPSM63610EVM.

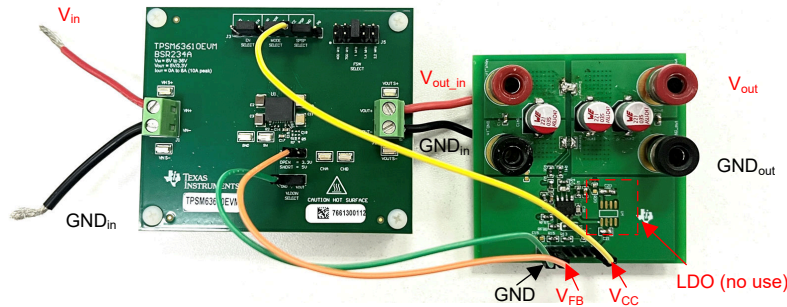


Figure 4-1. Physical Connection Diagram of CC/CV Board and TPSM63610EVM

### 4.2 Power Module (TPSM63610)

Figure 4-2 shows load regulation and the voltage setpoint with reducing output resistance of TPSM63610. Figure 4-3 shows the load and line regulation of TPSM63610.

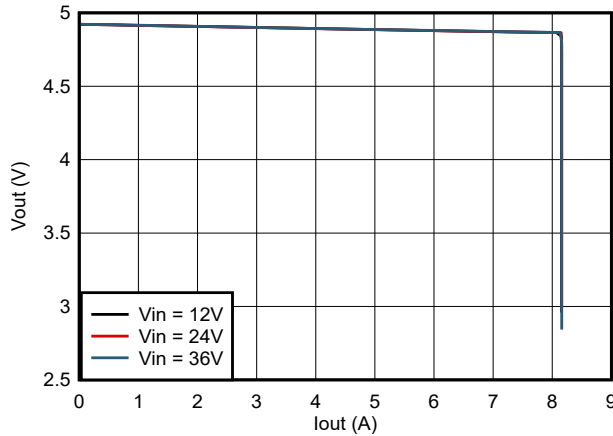


Figure 4-2. Load Regulation at Different  $V_{in}$  with Reducing  $R_{load}$  ( $V_{out} / I_{out}$ ) for TPSM63610

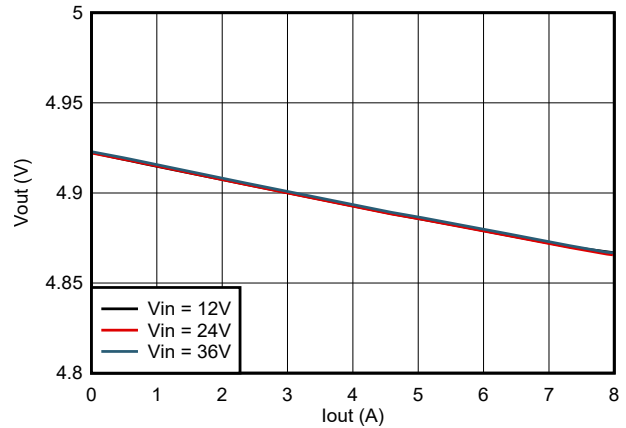


Figure 4-3. TPSM63610 Load and Line Regulation

Figure 4-4 shows the waveforms of SW (CH1),  $V_{out\_ripple}$  (CH2) and  $I_{out}$  (CH3) at 36 V ( $V_{in}$ ), 4 V ( $V_{out}$ ) at 8 A (CC mode).

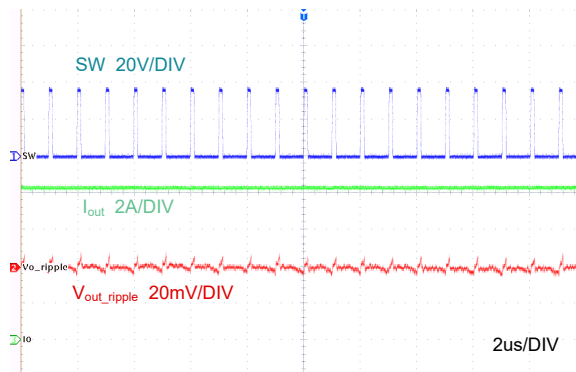


Figure 4-4. Steady-State Waveforms for TPSM63610

Figure 4-5 and Figure 4-6 show the load-transient performance  $V_{out}$  (CH4) and  $I_{out}$  (CH3) when stepping a constant resistive load from 10  $\Omega$  to 0.5  $\Omega$  (CV to CC) and 0.5  $\Omega$  to 10  $\Omega$  (CC to CV).

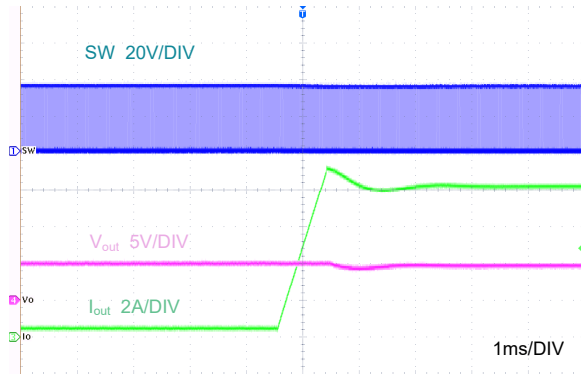


Figure 4-5. Load-Transient Performance for TPSM63610 (CV to CC)

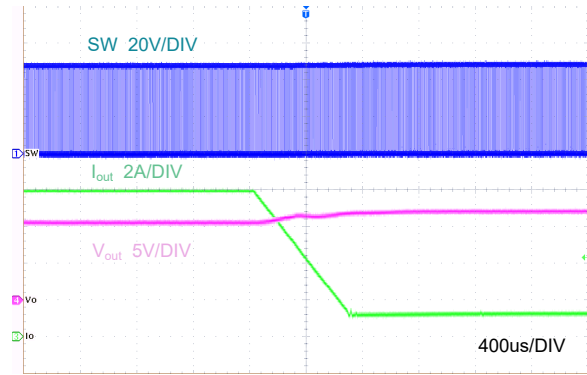


Figure 4-6. Load-Transient Performance for TPSM63610 (CC to CV)

### 4.3 Converter (LM61495)

Figure 4-7 shows load regulation and the voltage setpoint with reducing output resistance of LM61495. Figure 4-8 shows the load and line regulation of LM61495.

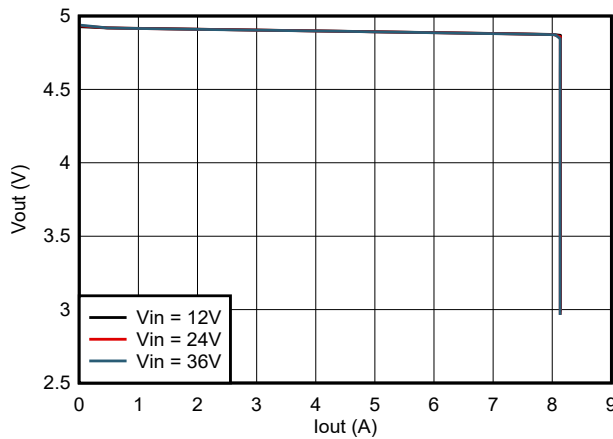


Figure 4-7. Load Regulation at Different  $V_{in}$  with Reducing  $R_{load}$  ( $V_{out} / I_{out}$ ) for LM61495

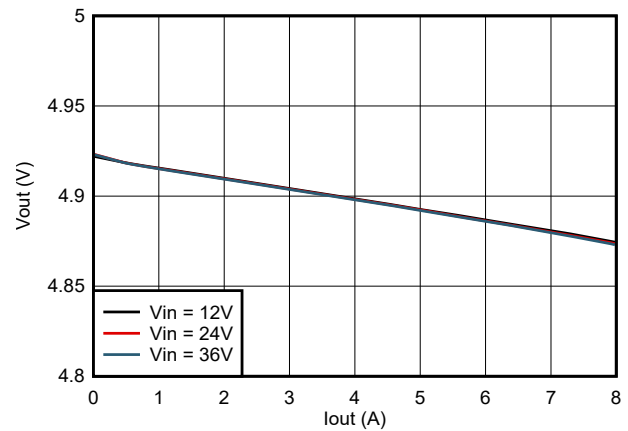


Figure 4-8. LM61495 Load and Line Regulation

Figure 4-9 shows the waveforms of SW (CH1),  $V_{out\_ripple}$  (CH2) and  $I_{out}$  (CH3) at 36 V ( $V_{in}$ ), 4 V ( $V_{out}$ ) at 8 A (CC mode).

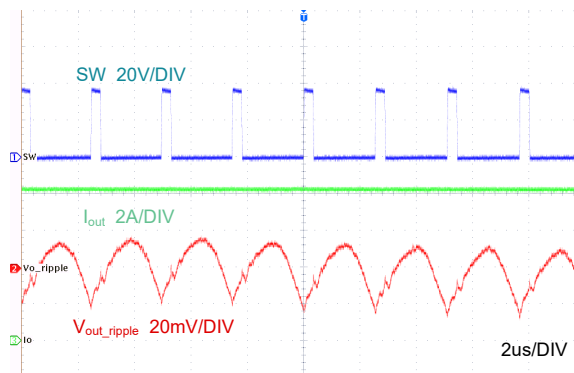


Figure 4-9. Steady-State Waveforms for LM61495

Figure 4-10 and Figure 4-11 show the load-transient performance  $V_{out}$  (CH4) and  $I_{out}$  (CH3) when stepping a constant resistive load from 10  $\Omega$  to 0.5  $\Omega$  (CV to CC) and 0.5  $\Omega$  to 10  $\Omega$  (CC to CV).

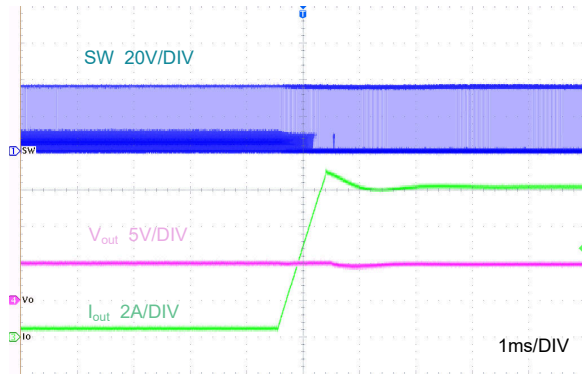


Figure 4-10. Load-Transient Performance for LM61495 (CV to CC)

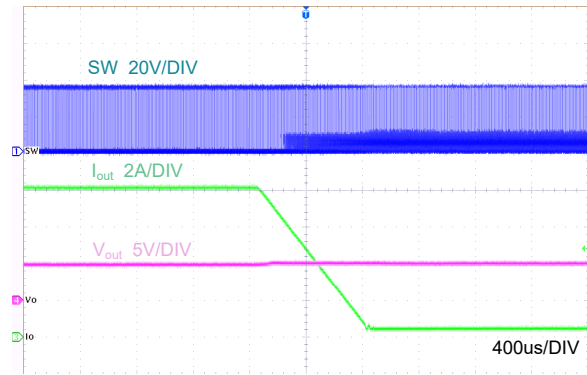


Figure 4-11. Load-Transient Performance for LM61495 (CC to CV)

#### 4.4 Controller (LM5149)

Figure 4-12 shows load regulation and the voltage setpoint with reducing output resistance of LM5149. Figure 4-13 shows the load and line regulation of LM5149.

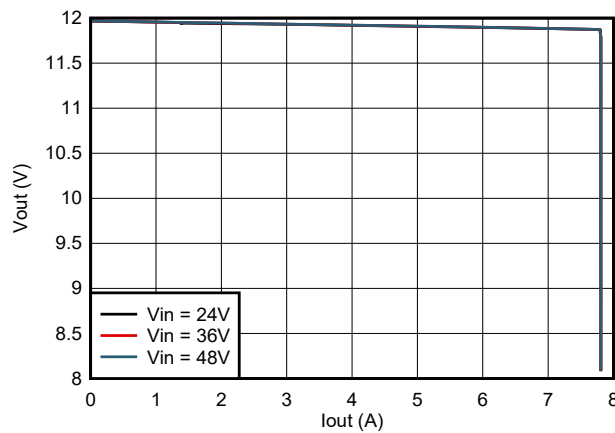


Figure 4-12. Load Regulation at Different  $V_{in}$  with Reducing  $R_{load}$  ( $V_{out} / I_{out}$ ) for LM5149

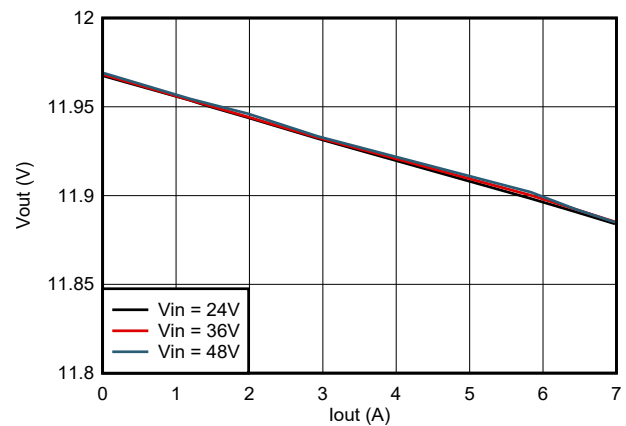


Figure 4-13. LM5149 Load and Line Regulation

Figure 4-14 shows the waveforms of SW (CH1),  $V_{out\_ripple}$  (CH2) and  $I_{out}$  (CH3) at 48 V ( $V_{in}$ ), 10.4 V ( $V_{out}$ ) at 8 A (CC mode).

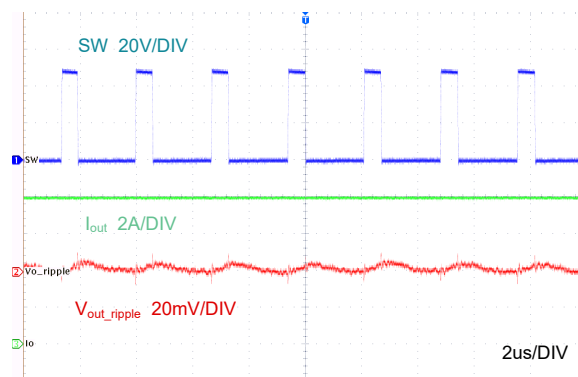
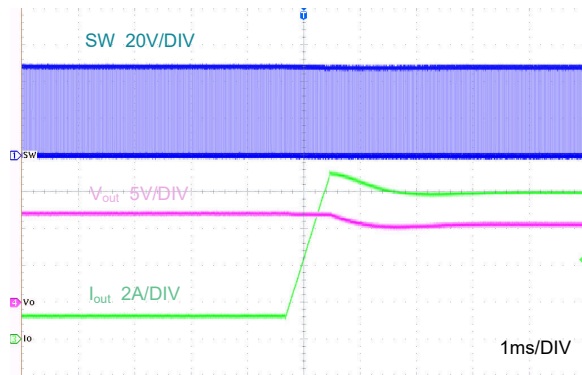
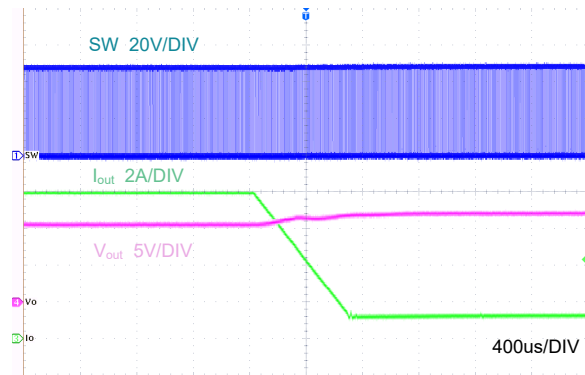


Figure 4-14. Steady-State Waveforms for LM5149

Figure 4-15 and Figure 4-16 show the load-transient performance  $V_{out}$  (CH4) and  $I_{out}$  (CH3) when stepping a constant resistive load from  $10\ \Omega$  to  $1.3\ \Omega$  (CV to CC) and  $1.3\ \Omega$  to  $10\ \Omega$  (CC to CV).



**Figure 4-15. Load-Transient Performance for LM5149 (CV to CC)**



**Figure 4-16. Load-Transient Performance for LM5149 (CC to CV)**

## 5 Summary

The CC/CV configuration circuit given in this article can basically be applied to all PCM controlled regulators. The overall circuit is relatively simple and has high versatility which can benefit for a cost-effective solution.

## 6 References

1. Texas Instruments, [How to Design a Simple Constant Current/Constant Voltage Buck Converter](#), application note.
2. Texas Instruments, [TPSM63610EVM Buck Regulator Evaluation Module's User's Guide](#).
3. Texas Instruments, [LM61495-Q1EVM EVM User's Guide](#).
4. Texas Instruments, [LM5149-Q1 Buck Controller Evaluation Module User's Guide](#).



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