Application Note

Reverse Current Operation of the LM5177 Buck-Boost Converter

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ABSTRACT

The LM5177 is a 4-switch buck-boost converter that supports seamless bi-directional operation, designed for applications like critical system power backups and energy storage from renewable sources. This application note provides a comprehensive guide on setting up the bi-directional current feature of the LM5177, offering clear design guidelines to help users get the most out of the device and optimize the performance in various scenarios. In Battery Backup mode, energy storage connected to the Vin of the LM5177 is charged with a constant current, managed by the built-in current limit features of the device and an external circuit using the TLV431 shunt regulator.

The TLV431 is used for limiting the charging voltage and controls the MODE pin with switching the converter between FPWM and PSM modes to maintain the desired storage voltage with minimal fluctuations. Tests using the LM5177 Buck-Boost Controller Evaluation Module show smooth transitions between constant current and constant voltage charging, with only minor ripple due to mode switching delays. The low operating current and reference voltage boost efficiency of the TLV431, and further adjustments to the MODE pin controller can enhance performance even more.

Overall, the capabilities of the LM5177 and the outlined control strategies offer a reliable design for efficient energy storage and management for a wide range of applications.

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Trademarks

1 Introduction

The LM5177 device is a buck-boost converter that also facilitates seamless bi-directional operation. This feature enables usage in various additional domains. For instance, the device can be used as a reliable power backup for critical systems or to store energy generated by renewable sources.

The primary objective of this document is to provide clear guidance on how to setup the operation for the bi-directional current feature of the LM5177 buck-boost converter. Through detailed design guidelines outlined in subsequent sections, users can gain insights into maximizing the device functionality and optimizing the performance in diverse settings.

The backup operation is effective only when the buck-boost controller is in FPWM mode. To activate this FPWM function, the mode pin of the controller must be set high. If the pin is not set high, the converter runs in PSM mode (forward operation). For Battery Backup mode, the backup energy storage is connected to the Vin of the LM5177. When the power backup operation is enabled and the output voltage exceeds the feedback threshold, the converter charges the storage element with a constant input current. This charging current can be controlled using the built-in current limit features of the buck-boost controller, including peak current limit and average current limit. The upper voltage charging limit needs to be controlled by an external circuit.

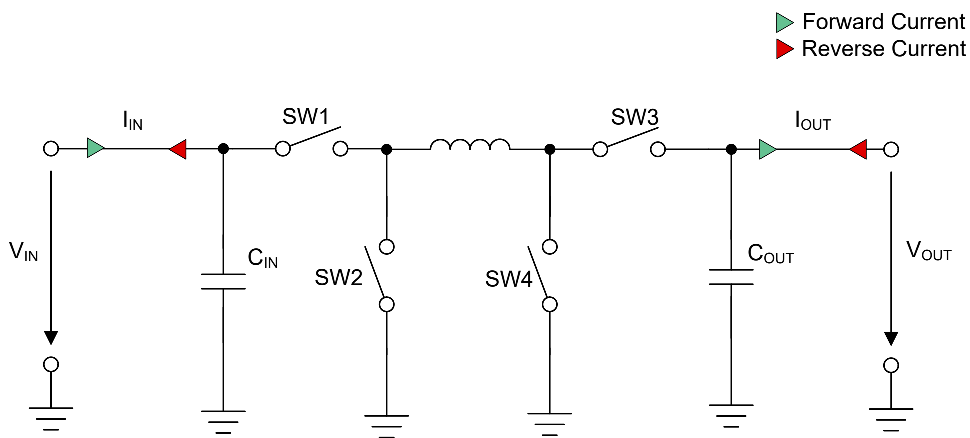

Figure 1-1. Overview of Bi-directional Current Flow Operation

2 Reverse Current Operation

The LM5177 device incorporates a precise inner voltage loop error amplifier, accurately reflecting the voltage at the COMP Pin onto the nominal peak current value of the inductor. This design provides effective voltage regulation.

Figure 2-1 illustrates the inner voltage loop of the buck-boost controller, featuring peak and average current sensing. The LM5177 data sheet provides detailed specifications and performance data for optimizing designs for efficiency and performance across applications.

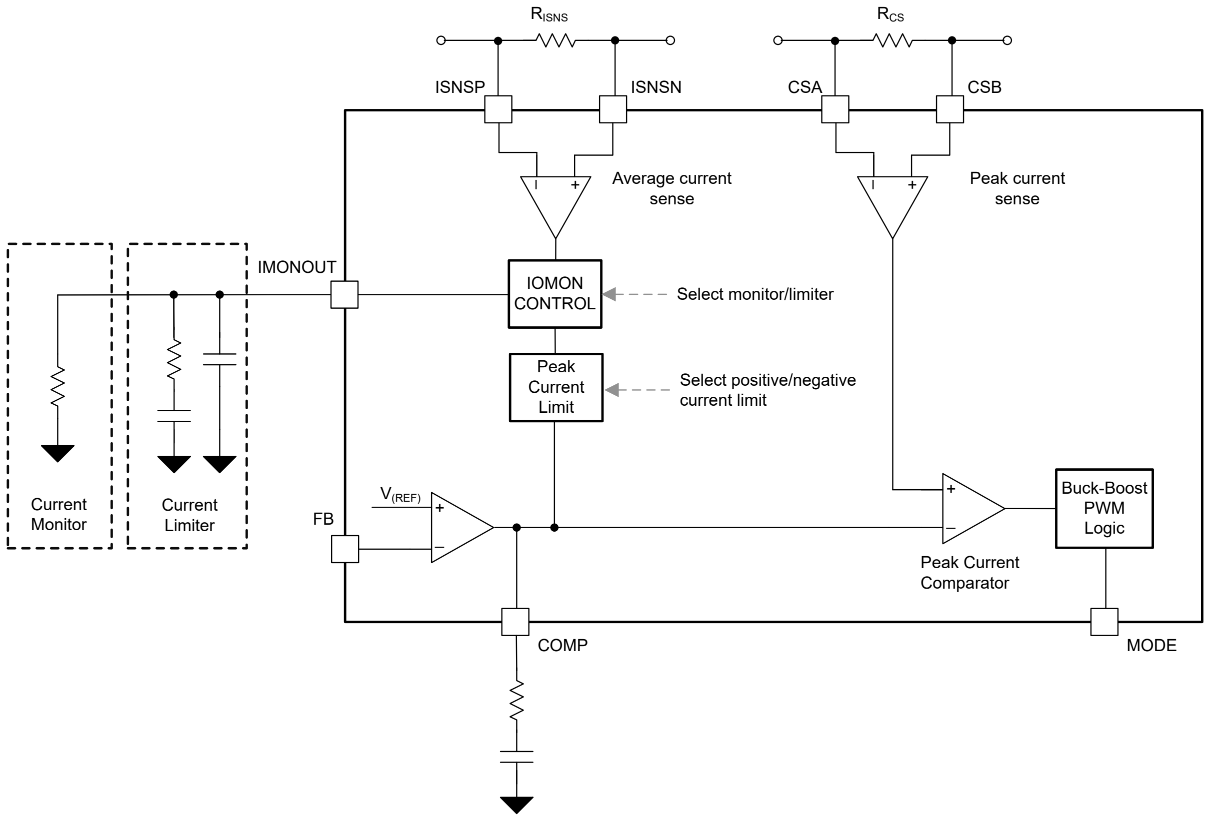

Figure 2-1. Control Loops for Buck-boost Controller

Figure 2-2 shows the inner voltage loop error for the voltage/current (V/I) characteristics of the amplifier. This graph illustrates how the voltage at the COMP pin V_{COMP} influences the direction of the converter current flow. Two threshold values are crucial, the $V_{comp,\ CL+}$ at 1.25V and $V_{comp,\ CL-}$ at 0.24V. If V_{COMP} exceeds the $V_{comp,\ CL0}$ threshold, which is typically 1.25V, the current flows forward through the converter. Conversely, if V_{COMP} falls below this threshold, the converter current flows in the reverse direction.

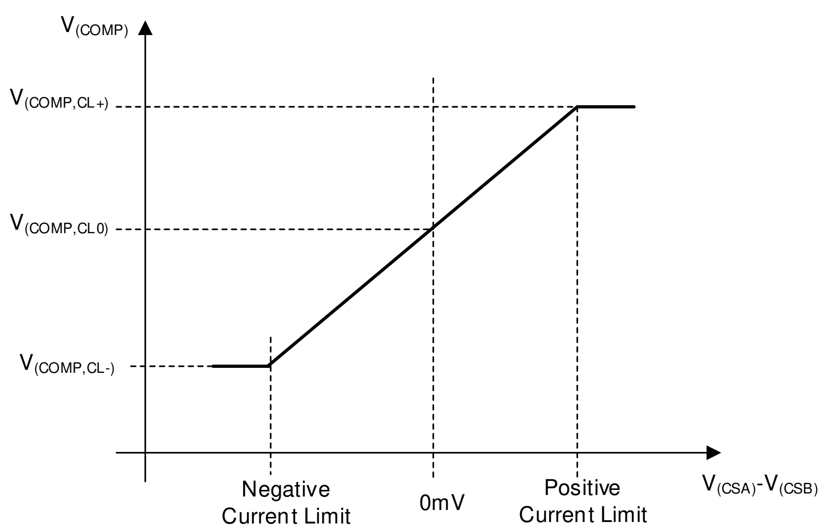

Figure 2-2. Control Function for the Peak Current Sense Voltage Versus V_{COMP}

Moreover, the peak current sense resistor sets the positive and negative limits for peak current. This resistor determines the maximum current that can flow in either direction through the converter. In addition, the average current limiter loop plays a pivotal role in controlling current flow. By adjusting the V_{COMP} value, this limiter loop can cap the forward or reverse current, verifying that the current remains within predefined limits. Understanding these V/I characteristics is crucial for designing and optimizing the performance of the buck-boost converter. By analyzing these parameters, the behavior of the converter can be adjusted to meet specific requirements and provide reliable operation across various conditions.

3 Design Considerations

Figure 3-1 shows the block diagram for reverse current operation. There are certain considerations to operate the LM5177 to operate in the reverse direction.

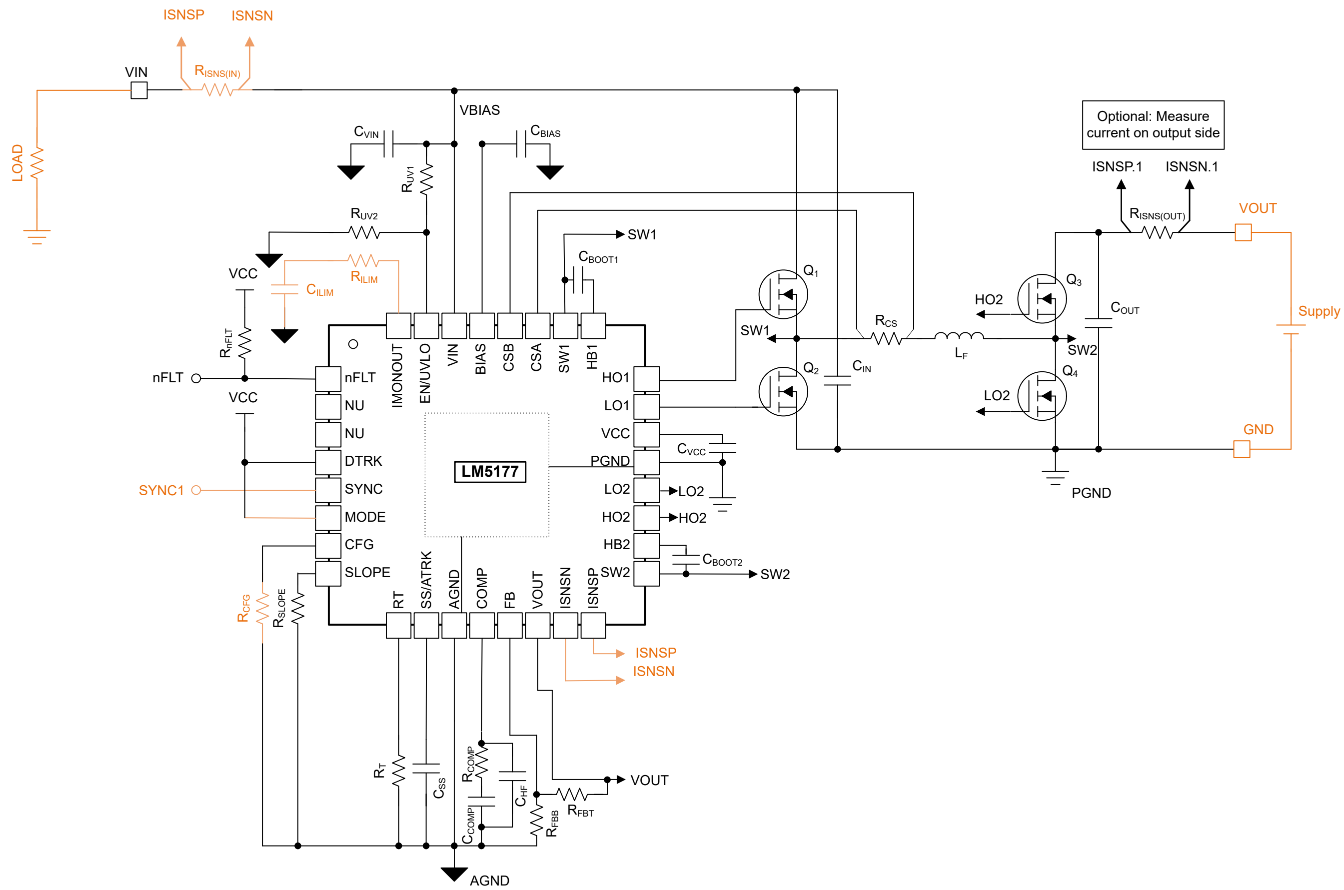

Figure 3-1. Block Diagram for Reverse Current Operation

If the device is used in a Backup System, charging needs to be limited once a defined voltage level is reached. A possible implementation is shown in Figure 3-2

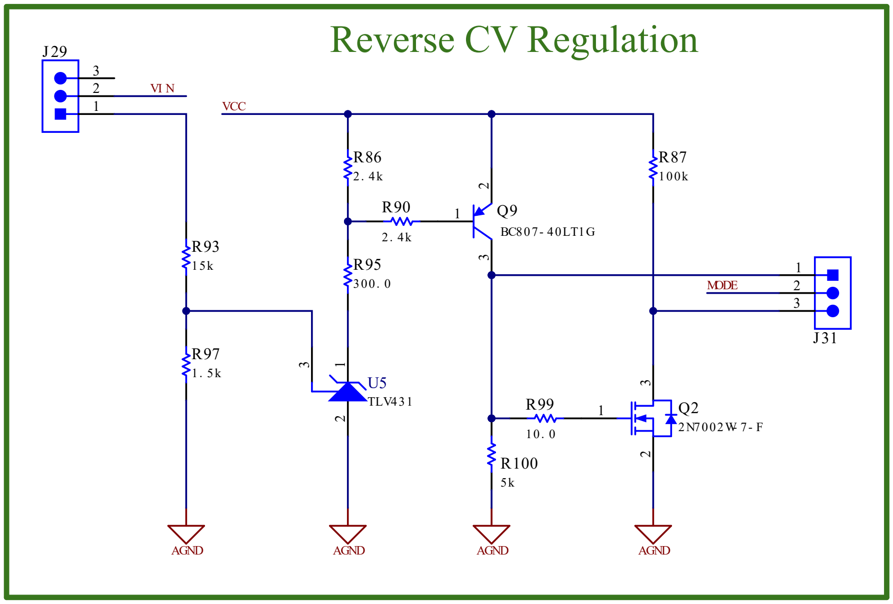

Figure 3-2. Block Diagram for Reverse CV Regulation Using MODE Pin Control

The TLV431 shunt regulator is used to stop charging on the defined maximum charge voltage level. An additional PNP Transistor is used to adjust the logic level of the MODE signal. When the biasing at the Vref pin of the TLV431 reaches 1.24V, the pin conducts and pulls the MODE pin low and puts the LM5177 into PSM mode which stops charging.

The resistors in the voltage divider must have high resistance to limit the reference current of the TLV431 and reduce power loss.

The storage element can be any type, such as batteries, capacitors, or super-capacitors. In this application note, dielectric capacitors are used as the storage element. In the design illustrated in Figure 3-2, the VCC voltage is 5V with a maximum supply current of 3A and the storage element charges to a constant voltage of 13.1V. This charging limit can be adjusted by changing the ratio of the voltage divider circuit. When the storage voltage reaches the desired voltages, the reference voltage from the voltage divider circuit rises to 1.24V, causing the cathode voltage of the TLV431 to drop from VCC to 1.8V.

When the cathode voltage decreases, the voltage forward biases the emitter-to-base terminals of the PNP transistor, which then lowers the emitter-to-collector voltage. This causes the gate-to-source voltage of the N-channel MOSFET to rise from 0V to VCC, turning the MOSFET on. As a result, the MODE pin voltage drops from VCC to 20mV. This change prompts the buck-boost controller to switch from FPWM mode to PSM mode, causing the storage to discharge. The discharging continues until the battery voltage hits the negative threshold of the hysteresis control. This process allows the storage voltage to stabilize around 13.1V, with minor fluctuations due to the switching delay of the MOSFET.

4 Pin Configurations

There are certain considerations to operate the LM5177 in the reverse direction.

The TLV431 shunt regulator is used to stop charging on the defined maximum charge voltage level. An additional PNP Transistor is used to adjust the logic level of the MODE signal. When the biasing at the Vref pin of the TLV431 reaches 1.24V, the pin starts conducting and pulls the MODE pin low and puts the LM5177 into PSM mode which stops charging.

Table 4-1 gives a summary of the LM5177 pins which must be considered especially for the reverse operation.

Table 4-1. Pin Configurations

PIN NAME	PIN FUNCTION	OBSERVATIONS
MODE	Mode Selection	The voltage at the pin determines whether the device operates in PSM mode (Mode < 0.41V) or FPWM mode (Mode > 1.19V).
FB	Feedback Reference	Sets the reference voltage for the voltage regulation loop.
EN / UVLO	Enable / Under Voltage Protection	Activates low voltage protection when the VIN voltage falls below the UVLO and enable threshold.
VIN	Input Voltages	The device becomes enabled when the VIN voltage exceeds the internal VDET voltage.
COMP	Reverse Current Regulation	Storage charging begins when the V(comp) value is less than V(comp, CL0), and constant voltage charging of the storage initiates when V(comp) equals or is greater than V(comp, CL0).
IMONOUT	Monitoring and Compensation	The pin monitors reverse current value or provides compensation for the average current loop.
SYNC	Synchronization Clock Input	For current limit in forward operation, SYNC pin needs to be connected to VCC, for reverse current limit operation, the pin needs to be connected to ground (Pulled Low) during the startup phase (EN/UVLO goes high).
CFG	Device Configuration Pin	Negative Current limit enabled for the reverse current operation.

4.1 Other Pin Configurations

For the reverse current operation, there are the following parameters, that need to be satisfied, for the typical operation of the LM5177 in reverse configuration.

1. The LM5177 must be operated in FPWM. To enable this mode, voltages higher than 1.19V must be applied to verify that the Mode Pin is set to High.
2. The device becomes enabled only, when the VIN voltage exceeds the internal V_{DET} voltage.
3. The output voltages of the converter must exceed the voltage threshold of the feedback pin (1.0V). If the output voltages are below the Feedback (FB) pin threshold, the converter functions in the standard forward mode.
4. Several undervoltage protection schemes, like UVLO (for Output) and V_{DET} (for Input), are available. Therefore, to allow reverse current operation and maintain device activation, the voltage at VIN and EN/UVLO must exceed the respective minimum programmed voltage thresholds.

To verify typical operation of the LM5177, at first, the device must be enabled by providing input voltages at Vin greater than the internal V_{DET} Voltages. For this purpose, 5V is supplied at the input externally using a voltage supply, verifying that the input voltages are greater than the internal V_{DET} voltages.

4.1.1 MODE Pin

The threshold voltages for FPWM and PSM modes are 1.19V and 0.41V, respectively. When the voltage at the MODE pin rises above 1.19V, the converter switches to FPWM mode, allowing backward operation and causing the storage element to charge. Conversely, when the voltage falls below 0.41V, the converter operates in forward mode only and stops the charging.

4.1.2 IMONOUT

The IMONOUT pin have two functions in reverse current operation. The first function is that the pin can be used to monitor the reverse current value when the average current limit feature is not enabled. In this case, a pulldown resistor is needed between IMONOUT pin and GND. The second function is that this pin is also used to provide a compensation to an average current limit loop to limit the reverse current. In this case, a compensation network is required at IMONOUT pin.

5 Application Measurements

To verify that the designed controllers for the MODE pin work correctly, tests are conducted using the LM5177 Buck-Boost Controller Evaluation Module. The results, displayed in Figure 5-1 through Figure 5-4, demonstrate a smooth shift from constant current to constant voltage charging of the storage element when using the MODE pin control. However, a small hysteresis, caused by the switching delay of the MOSFET, is noticeable during the transitions between FPWM and PSM modes, leading to a minor ripple in the charging voltage. An initial bias of 5V is applied to the storage element to bypass the internal low voltage protection of the controller. When the storage voltage reaches the desired voltages, the reference voltage from the voltage divider circuit rises to 1.24V, causing the cathode voltage of the TLV431 to drop from VCC to 1.8V.

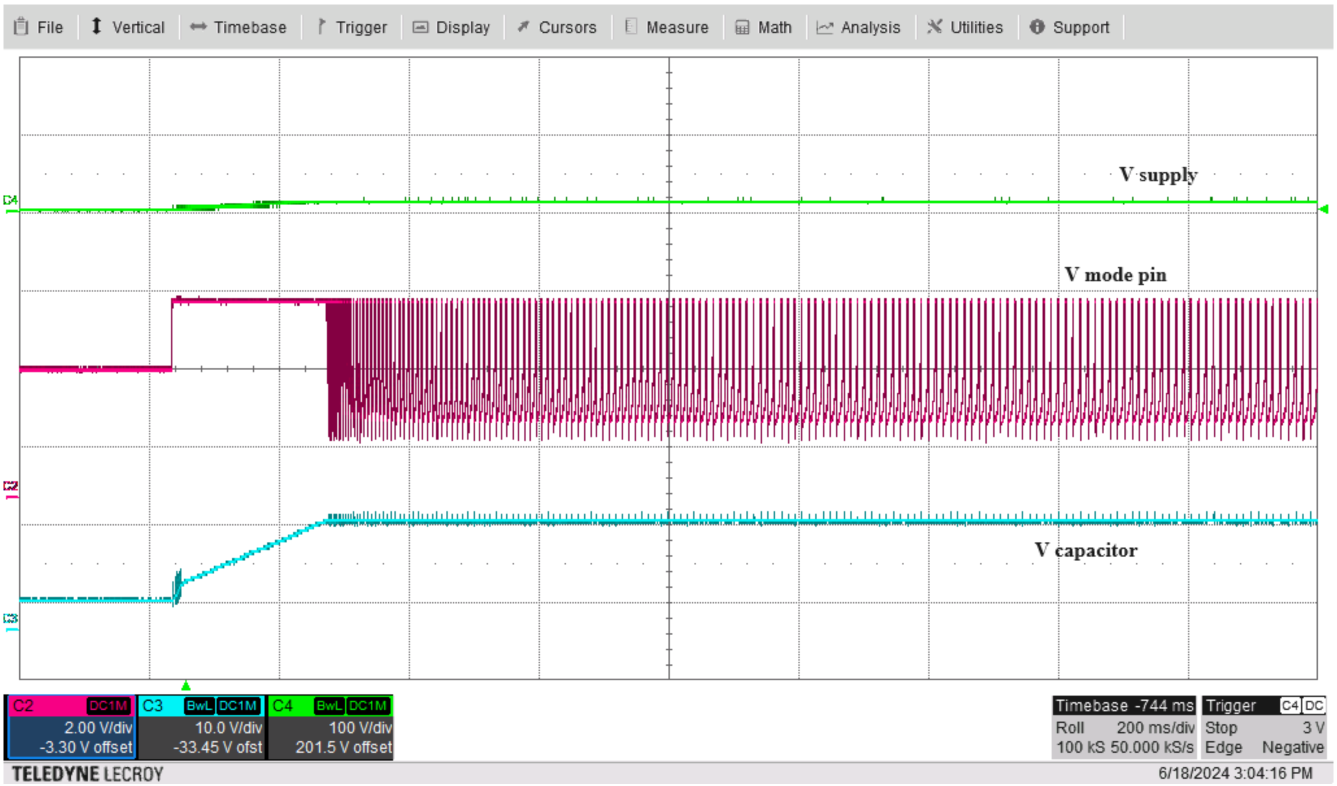

Figure 5-1. Constant Voltage Charging

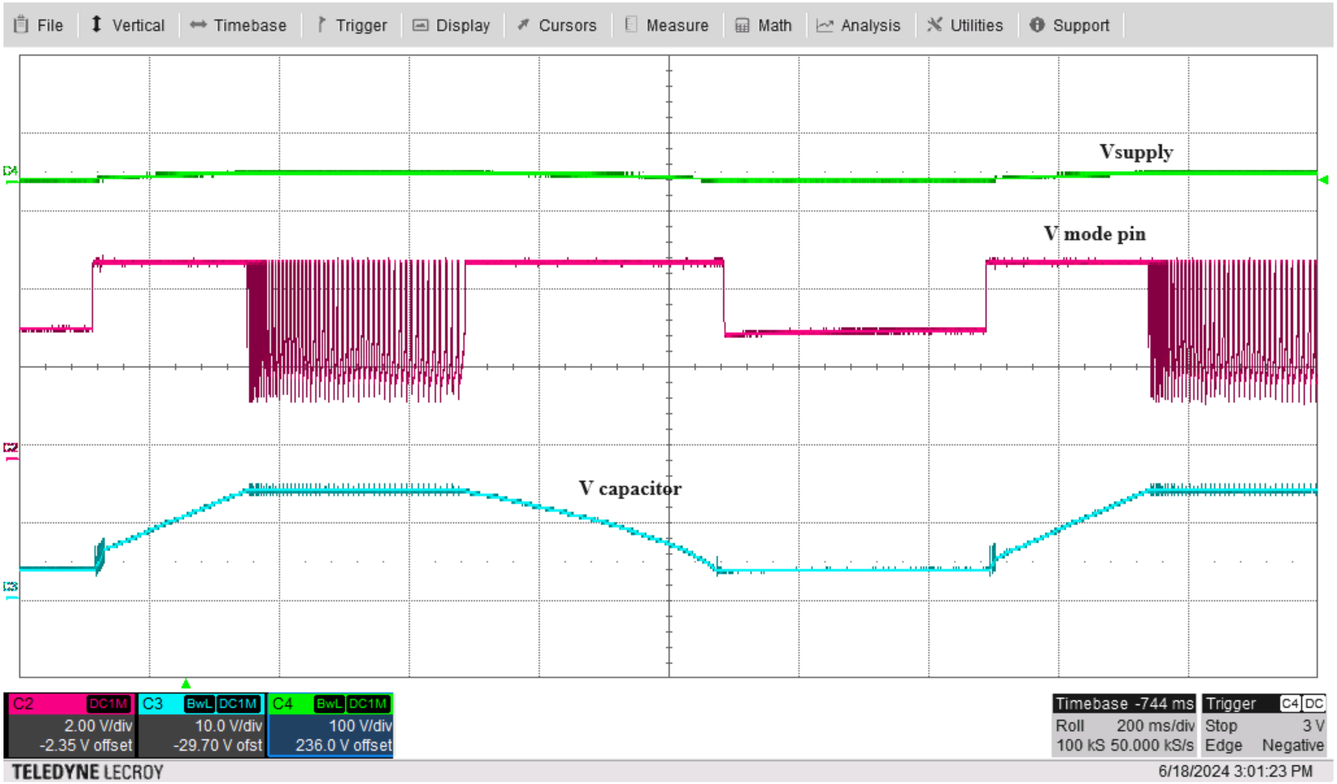

Figure 5-2. Constant Voltage Charging and Discharging

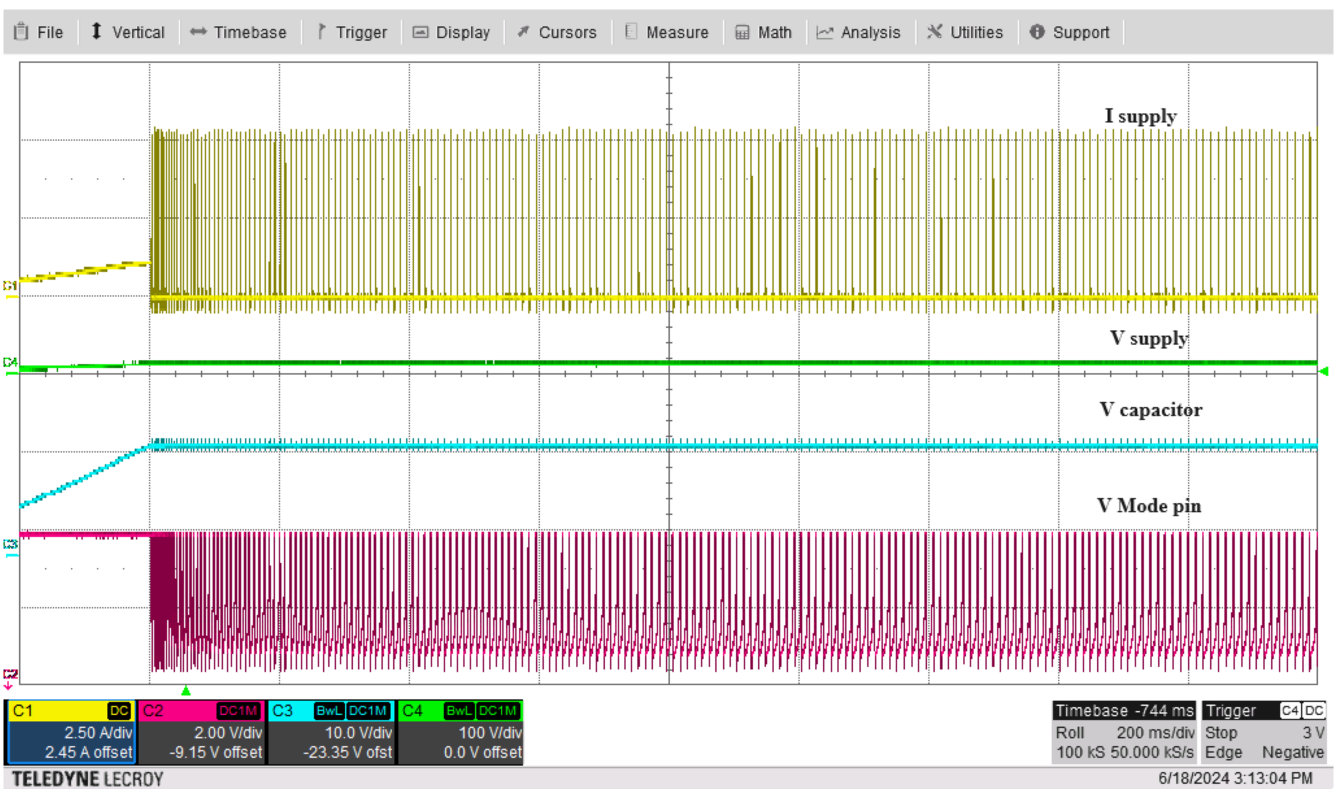

Figure 5-3. Constant Voltage Charging With Supply Current

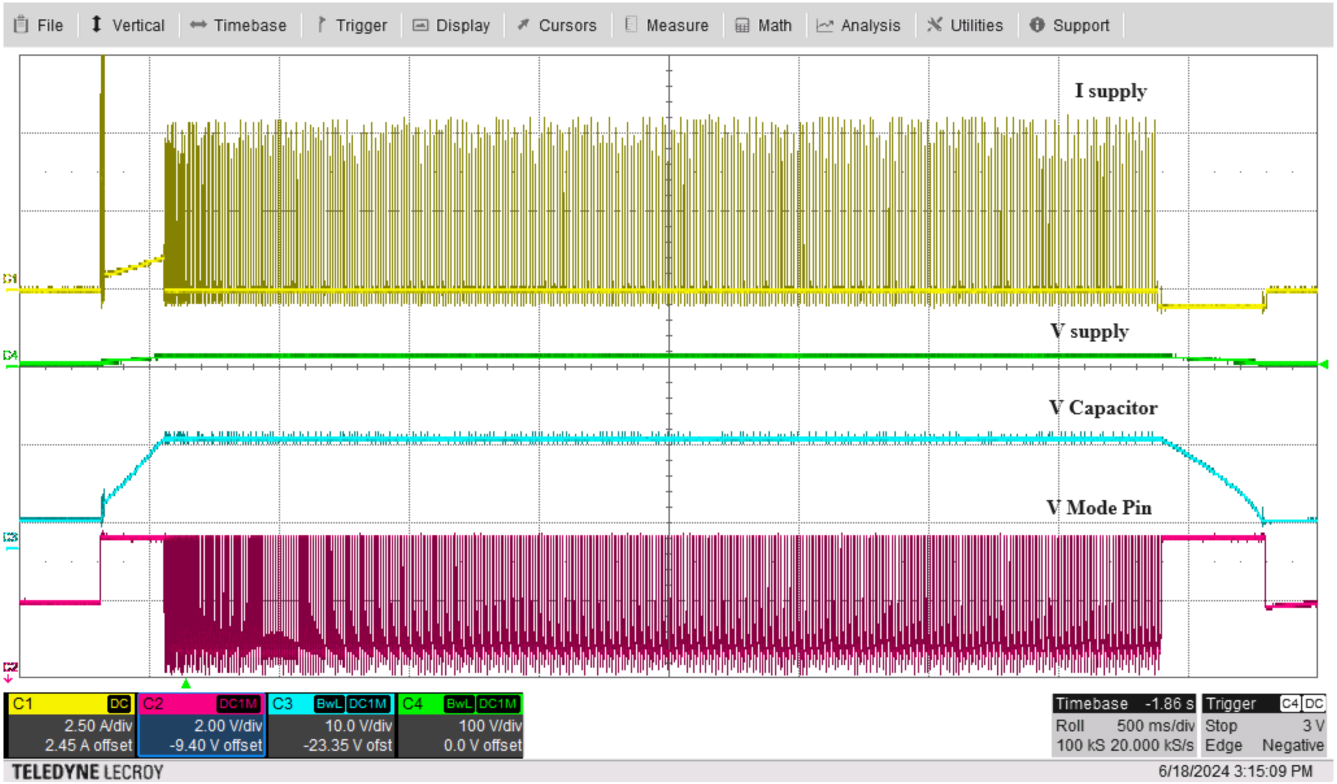

Figure 5-4. Constant Voltage Charging and Discharging With Supply Current

6 Summary

The previous results showed how smoothly the storage voltage is regulated during constant voltage charging using the MODE pin controls. This smooth operation makes these features an excellent choice for any application to design. Here, TLV431 is used as a shunt regulator, with a lower operating current and reference voltage, to boost the efficiency and reduce the supply current of the designed controllers

Additionally, different levels of hysteresis can be introduced to the MODE pin controller. This can be accomplished by adding a small parallel current source to the voltage divider circuit or by placing a small capacitor between the gate and source of the MOSFET. These adjustments help fine-tune the performance of the controller and can further increase the efficiency.

7 References

For related documentation see the following:

- Texas Instruments, LM5177 80V Wide VIN Bidirectional 4-Switch Buck-Boost Controller data sheet.
- Texas Instruments, TLV431x Low-Voltage Adjustable Precision Shunt Regulator data sheet.
- Texas Instruments, LM5177 BuckBoost Quickstart Calculator Tool.
- Texas Instruments, A Simple Constant Voltage Regulation Using the MODE Pin application brief.
- Texas Instruments, Constant Current Operation Using the Internal Current Limiter application brief.