Application Brief

Implementing Reverse Current Operation in the LM51772 Using MODE Function

TEXAS INSTRUMENTS

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Introduction

The LM51772 is a four-switch buck-boost controller designed to support reverse current operation (RCO) through the MODE function. This capability allows the converter to store excess energy at the output, making this highly valuable in applications where energy recovery or backup power is required. Typical use cases include regenerative energy capture during motor braking, battery backup systems during a main power outage, and so on.

This application brief describes the implementation of MODE pin control used to enable RCO operation in the LM51772. In this brief, the MODE pin is driven by a hysteresis controller implemented with a simple comparator circuit. The controller activates RCO when the output voltage exceeds the defined threshold. For the LM51772 specifically, RCO is automatically disabled when the feedback (FB) voltage falls below the device reference voltage (Vref), meaning hysteresis control is not strictly required for proper operation. However, a hysteresis controller is included in this implementation to maintain design compatibility with LM5177 and LM51770 devices, which require hysteretic MODE control to make sure RCO operation is stable.

The LM51772 device allows RCO configuration through either the R2D interface or the I²C interface. While detailed configuration options for RCO are discussed in *Battery or Capacitor Backup Operation with the LM51772*, this brief focuses on configuring RCO using the I²C interface.

MODE Function

The LM51772 device operates in two primary modes: Power-Save Mode (PSM) and Forced PWM (FPWM) mode. The detail about these modes is well explained in LM51772 55V 4-Switch Buck-Boost Controller with I2C Interface. Reverse current operation is only supported when the device is configured in FPWM mode. These mode selection is controlled by the MODE pin. When the MODE pin voltage rises above the positive-going threshold (V_{T+MODE}), the device transitions from PSM to FPWM mode, enabling RCO.

To initiate RCO, the configuration settings listed in the Table 1 must be properly applied, as described in detail in *Battery or Capacitor Backup Operation with the LM51772*. The corresponding pin connections are illustrated in Figure 1. When the output supply or energy source increases the feedback (FB) voltage beyond the reference threshold (V_{REF}), the MODE pin control detects the rise in output voltage and drives the MODE pin high, above the V_{T+MODE} threshold. This action enables the LM51772 device to transfer excess output energy to the storage element connected at the input of the converter.

Table 1. Pin Configuration for LM51772 Device

MODE Pin	Above V_{T+MODE} threshold
Feedback Pin (FB)	Above V_{ref} threshold
nRST Pin	Above $V_{T+(nRST)}$ threshold
UVLO Pin	Connect to output or external supply
BIAS Pin	Connect to output or external supply
VDETs	Turn off (if the votlage of the input storage element is below VDET positive-going threshold)

Figure 1. Schematic for the RCO via I²C configuration

Once the configurations in Table 1 are fulfilled and the voltage on the MODE pin is high, the LM51772 enables RCO operation and regulates a constant negative current through the average current regulation loop. The magnitude of this average negative current is determined by the current-sense resistor connected to the ISNSx input pins and by the average current-limiter settings programmed through the I²C interface.

These settings can be modified by programming the MFR_SPECIFIC_D0 register through the LM51772 internal DAC, specifically through the IMON_LIMITER_EN and EN_NEG_CL_LIMIT bits. In addition, a compensation network connected to the ILIMCOMP pin is required to verify stable average current-limit operation. Alternatively, the average current limiter can be configured through the R2D interface at the I_{SET} pin of the LM51772. This topic is discussed in detail in this *Battery or Capacitor Backup Operation with the LM51772*.

Once the RCO initiated, the device continues charging the storage element at a constant negative current until the storage voltage reaches the input voltage regulation (IVR) threshold. At this point, control transitions to the IVR loop, which regulates the input voltage to the programmed set point. Detailed configuration guidelines for the IVR function are provided in *Battery or Capacitor Backup Operation with the LM51772*.

MODE Pin Control

To verify accurate MODE pin triggering, a small hysteresis of ±250mV is applied to the output voltage (V_{OUT}). This creates an upper threshold, $V_{OUT(H)} = V_{OUT} + 250mV$, and a lower threshold, $V_{OUT(L)} = V_{OUT} − 250mV$. When the output voltage rises and reaches the upper threshold, $V_{OUT(H)}$, the controller drives the MODE pin above V_{T+MODE} threshold, initiating RCO. Once RCO is initiated, the operation continues independently of any subsequent changes in the MODE pin state.

To terminate RCO, the device output voltage (represented by the feedback signal (FB)) must fall below the reference voltage (V_{REF}) threshold. This condition occurs only when the power source connected to the converter output is depleted and the V_{out} begins to decrease. For the LM51772, this requires the $V_{OUT(L)}$ threshold, to be equal to the V_{out} programmed via the I²C interface. If this condition is not met, the MODE pin does not fall below the negative-going threshold ($V_{T−MODE}$), and the converter remains in FPWM mode.

In contrast, for other LM5177x devices, RCO terminates immediately when the MODE signal falls below the $V_{T−MODE}$ threshold. In those devices, the $V_{OUT(L)}$ level can be selected independently of the feedback signal and the V_{REF} threshold.]

Hysteresis Controller

As discussed earlier, the LM51772 does not require a $V_{OUT(L)}$ threshold for MODE pin control, since RCO terminates only when the FB signal falls below the V_{REF} threshold. As a result, a simple comparator circuit without hysteresis can be used for MODE pin control with the LM51772.

However, other devices such as LM5177 and LM51770 require hysteresis on the MODE pin to verify proper RCO operation. To support these devices, a hysteresis controller is implemented in this design. The controller uses an open-drain comparator (TLV3401) with a positive-feedback resistor network to generate the required hysteresis. Figure 2 shows the schematic of the implemented hysteresis controller.
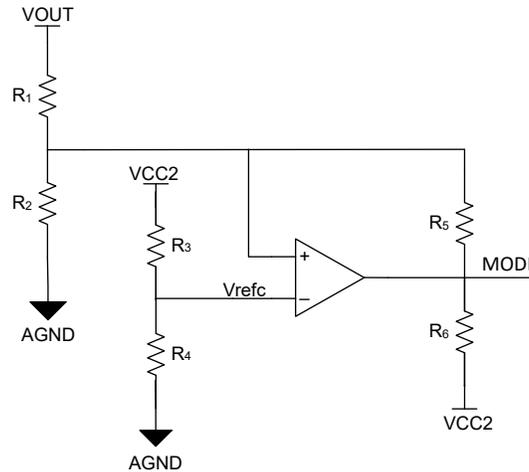

Figure 2. Hysteresis Controller

The controller compares the signal at the non-inverting input with the reference voltage (V_{refc}) applied to the inverting input of the comparator. When the non-inverting input voltage exceeds the inverting input voltage, the comparator output transitions high; otherwise, the input voltage remains low. The signal applied to the non-inverting input consists of two components: a positive-feedback signal defined by resistor R5, which sets the hysteresis magnitude, and a scaled version of the output voltage determined by the resistor divider formed by R1 and R2. Equation 1 is used to calculate the desired V_{refc} value, while Equation 2 and Equation 3 determine the upper and lower hysteresis thresholds, $V_{OUT(H)}$ and $V_{OUT(L)}$, respectively, relative to VOUT.

$$V_{refc} \;=\; \frac{R_4}{R_4 \;+\; R_3} * V_{CC2} \tag{1}$$

$$V_{out(H)} = \frac{V_{refc} \; * \; \left(R_2 R_5 \;+\; R_1 * \left(R_5 + R_2\right)\right)}{R_2 R_5} \tag{2}$$

$$V_{out(L)} = \frac{R_1 \; * \; \left(V_{refc} * \left(R_6 + R_5\right) \;-\; R_2 * \left(V_{cc2} - V_{refc}\right)\right)}{R_2 * \left(R_6 + R_5\right)} + V_{refc} \tag{3}$$

In this design, the V_{OUT} is set to 21.75V, with a hysteresis of 250mV applied to define the upper and lower thresholds. This results in $V_{OUT(H)}$ = 22.25V and $V_{OUT(L)}$ = 21.75V. The reference voltage, Vrefc, is set to 2.5V, and the supply voltage, V_{CC}, is 5V. Based on these parameters, the calculated values for resistors R1 through R6 are as follows: R1 = 102kΩ, R2 = 13kΩ, R3 = 102kΩ, R4 = 102kΩ, R5 = 1.07MΩ, and R6 = 20kΩ.

Results

[Figure 3](#) shows that RCO is initiated when the output voltage exceeds the $V_{OUT(H)}$ threshold. At this point, the comparator drives the MODE pin above the V_{T+MODE} threshold, thereby enabling RCO. The storage element, implemented with capacitors, is charged by a constant current until the voltage reaches the input voltage regulation (IVR) threshold, after which it is regulated to 12V. [Figure 4](#) demonstrates that RCO operation remains unchanged even if the MODE pin falls below the V_{T-MODE} threshold. [Figure 5](#) indicates that RCO is disabled when the feedback signal drops below the Vref threshold while the MODE pin remains above the V_{T+MODE} threshold. [Figure 6](#) illustrates that a drop in the feedback signal below the V_{ref} threshold causes the MODE pin to fall below the V_{T-MODE} threshold, as $V_{out(L)}$ is equal to the set output voltage.
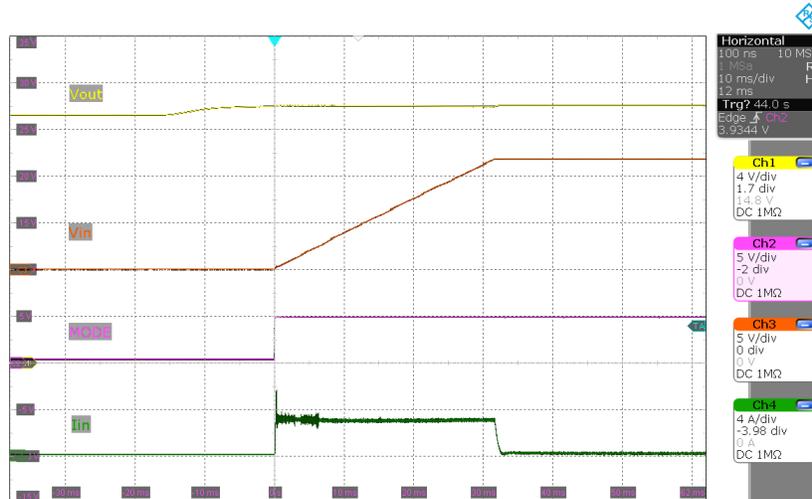
Figure 3. MODE Pin Above V_{T+MODE} Threshold
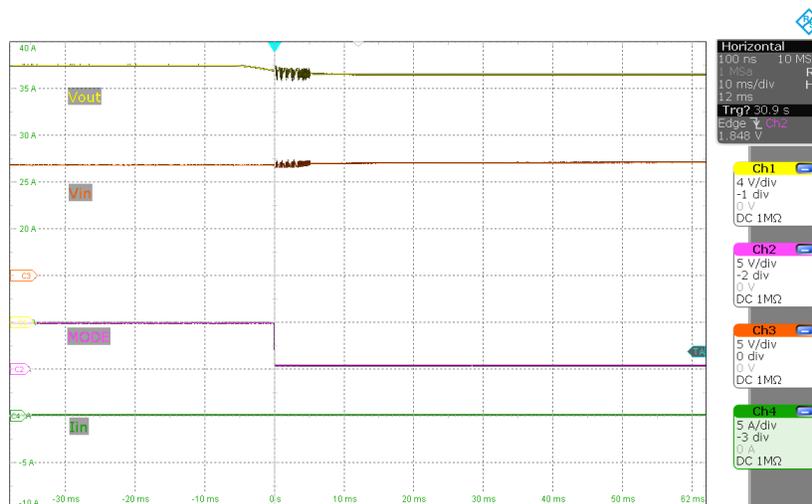
Figure 4. MODE Pin Below V_{T-MODE} Threshold During RCO

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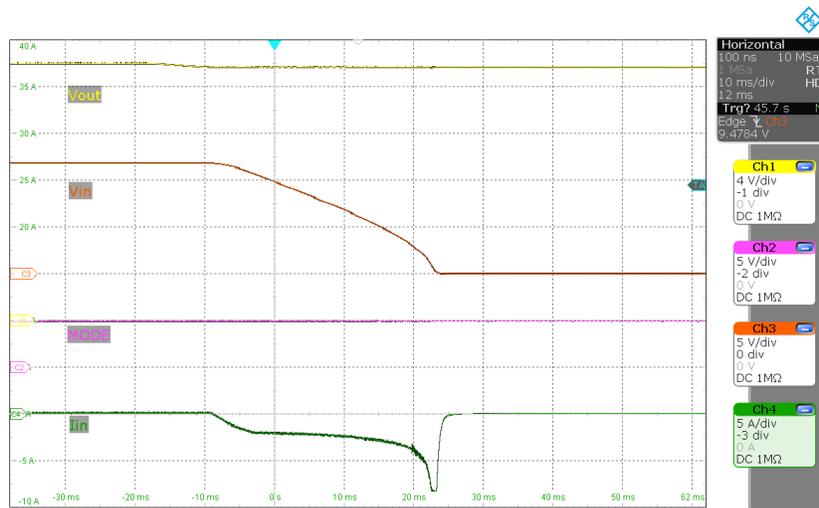
Figure 5. Feedback Signal Below V_{ref} Signal ($V_{out} < V_{out(L)}$)
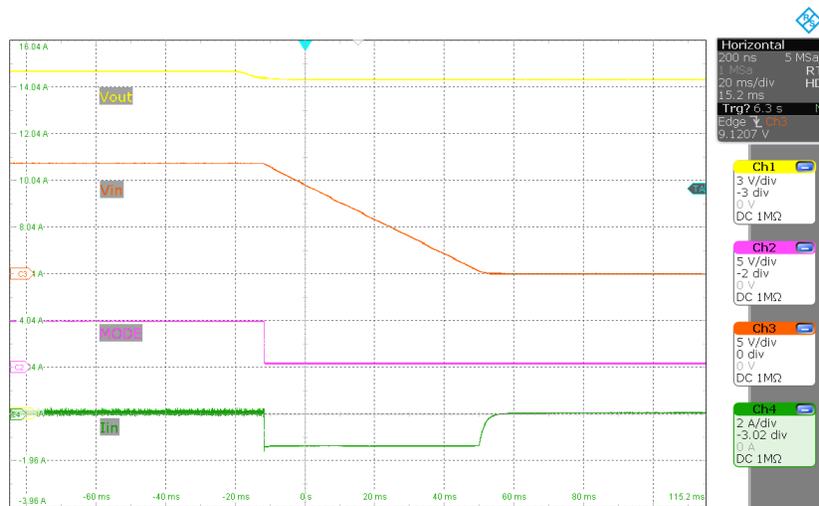
Figure 6. MODE Pin Below $V_{T\text{-}MODE}$ Threshold and V_{out} Signal Below $V_{out(L)}$ Threshold

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