Application Note

How to Operate the Two Channels of LM5171 Independently

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ABSTRACT

The LM5171 is a dual channel bidirectional average current mode controller. The two channels of LM5171 are independent. It is possible to configure the two channels as dual buck, dual boost or even one buck with one boost. However, some extra care must be taken when operating the two channels independently.

This application note shows the circuit differences between the two channels of LM5171. The missing features of CH2 for a complete converter are summarized when operating independently. The design requirements of the external circuits are analyzed. Two typical applications of using the two channels of LM5171 are discussed: two independent Constant Current/Constant Voltage (CC/CV) chargers and a bidirectional buck-boost converter. Detailed block diagrams are shown, and some design tips are provided.

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1 Introduction

The LM5171 is a dual channel interleaved bidirectional (buck or boost) controller utilizing average current mode control. Precise current sense amplifiers are integrated for precise current regulation. The robust 5A half-bridge gate drivers can drive high power MOSFETs. The controller can be dynamically programmed to operate in either the diode emulation mode (DEM) or forced pulse width modulation mode (FPWM). Two error amplifiers, a 3.5V voltage reference (VREF) and 5V bias supplies (VDD) are integrated. Versatile protection features include cycle-by-cycle current limiting, overvoltage protection (OVP), over temperature protection and urgent shutdown latch. The I^2C interface supports monitoring and diagnosis during operation.

Average current mode control gives the benefit to regulating the average inductor current precisely. Constant current operation can be obtained by controlling ISET1 and ISET2 (ISETx) voltage. In multiphase operation, current sharing is achieved by connecting ISETx pins together.

The LM5171 supports independent channel operation. Each channel has dedicated DIRx, ISETx, ENx, SS/DEMx pins to fulfill independent control. The two channels of LM5171 can be configured as dual buck, dual boost or even one buck with one boost. It is possible to build two independent CC/CV battery chargers with a single LM5171. Also, it is possible to achieve bidirectional buck-boost conversion with a single LM5171: a boost converter cascaded by a buck converter. The block diagram of the two-stage converter is shown in Figure 1-1.

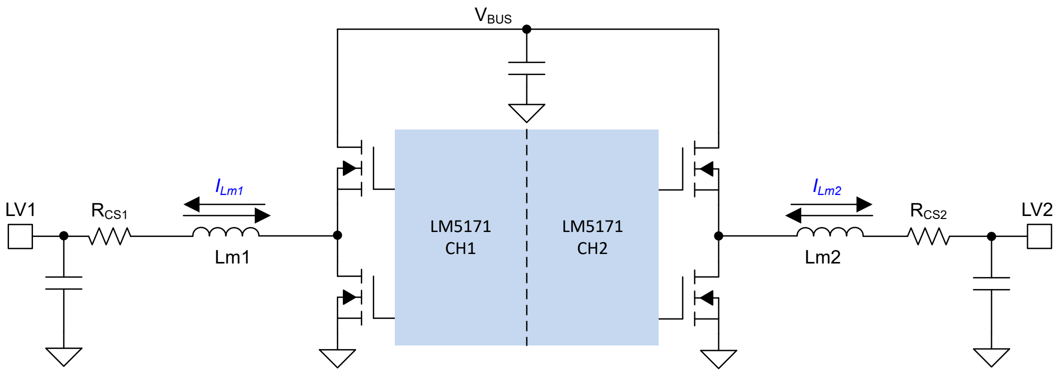

Figure 1-1. Bidirectional Buck-Boost with Single LM5171

2 Circuit Differences Between Channels

The LM5171 Channel 1 (CH1) and Channel 2 (CH2) have identical pinout but slightly different functions. Figure 2-1 shows the circuit differences between CH1 and CH2. The key differences are:

- DIR1 determines whether the HV error amplifier or LV error amplifier is active.
- When CH1 is inactive, VSET is pulled low.
- When OVP triggers, VSET and SS/DEM1 are pulled low.

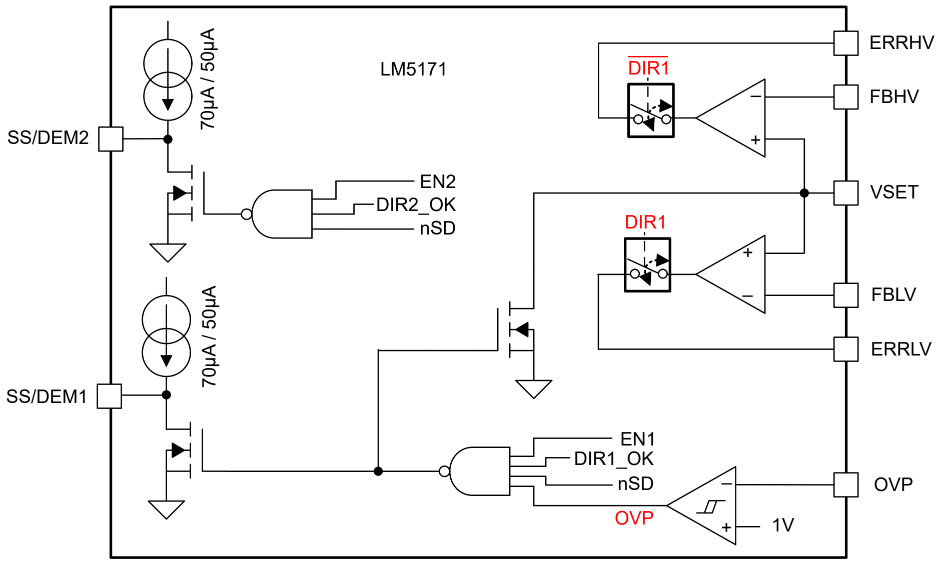

Figure 2-1. Circuit Differences between CH1 and CH2

When CH1 and CH2 are operated independently, CH1 has all the necessary features for a complete bidirectional converter: two error amplifiers for HV and LV rail voltage regulation, OVP with hysteresis, precise voltage reference with soft start. When operating CH2 in voltage mode, these features need to be implemented by external circuits.

3 Design of External Error Amplifier Circuit

When operating CH2 in voltage mode, external error amplifiers are required. Figure 3-1 shows the block diagram of the two channels. External error amplifiers OPA1 and OPA2 are used for CH2.

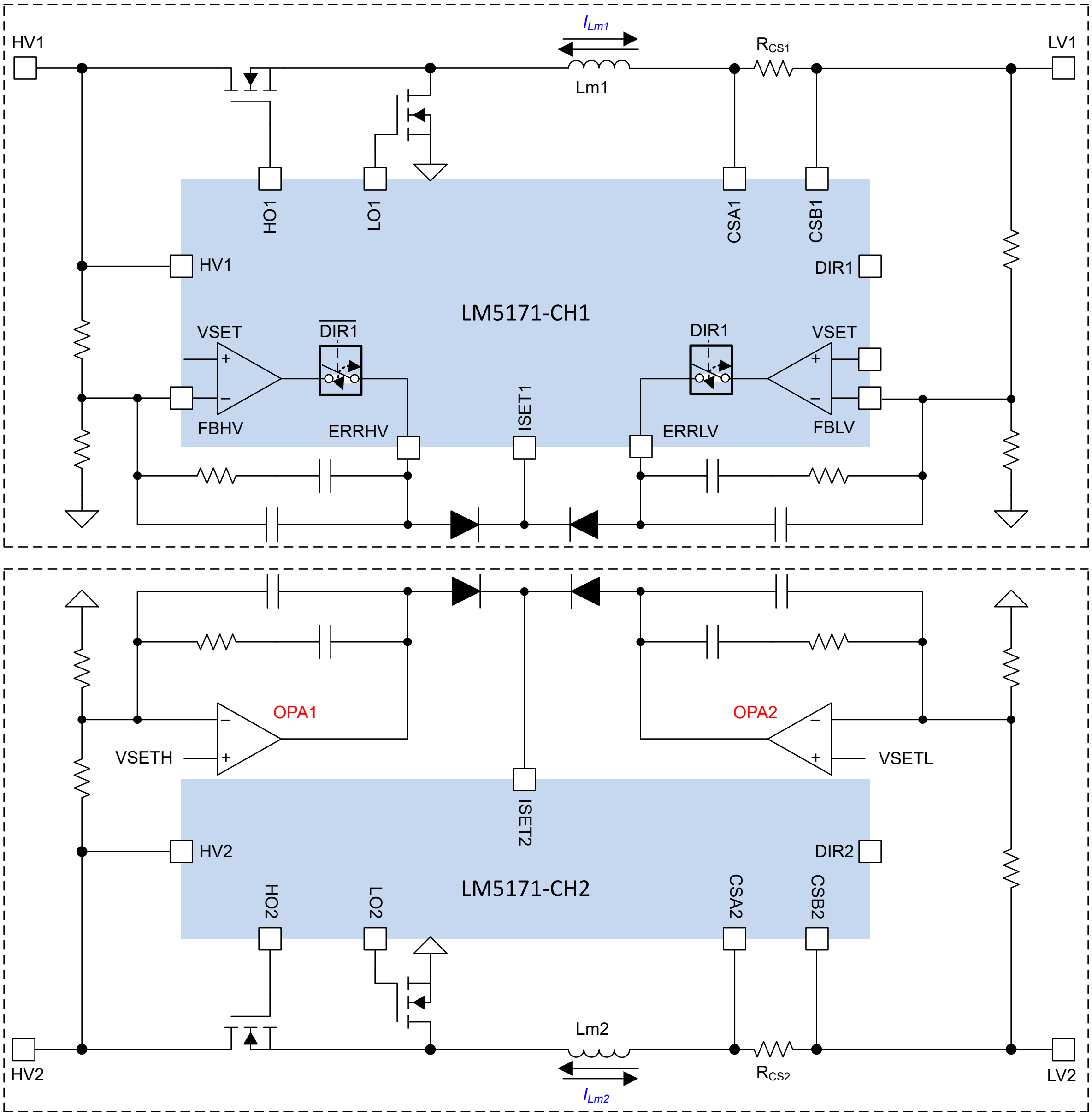

Figure 3-1. Two Channels of LM5171 with External Operational Amplifiers for CH2

Consider the features below when designing the external error amplifier circuit,

- The handover of the two loops when two outer loops are used.
- The soft start of the reference voltages (VSETH and VSETL).

An example is shown in Figure 3-2.

Two common cathode diodes are used, so that the error amplifier with higher output voltage takes over the loop.

Supply the error amplifiers and logic gates with LM5171 VDD pin. The VDD pin is the output of the internal 5V linear regulator. Do not draw more than 10mA from VDD.

The VREF pin is a 1% tolerance 3.5V voltage reference with a load capacity of 2mA. Use resistor dividers from VREF pin to set the reference voltages (VSETH and VSETL).

Pay attention to the operational amplifier common mode input voltage range when selecting VSETH and VSETL voltage level. With the supply of VDD, widely used operational amplifiers like LM358 series have a common mode input voltage range of 0V to VDD-2V over temperature. In this case, 1V to 2.5V is a reasonable range for VSETH and VSETL.

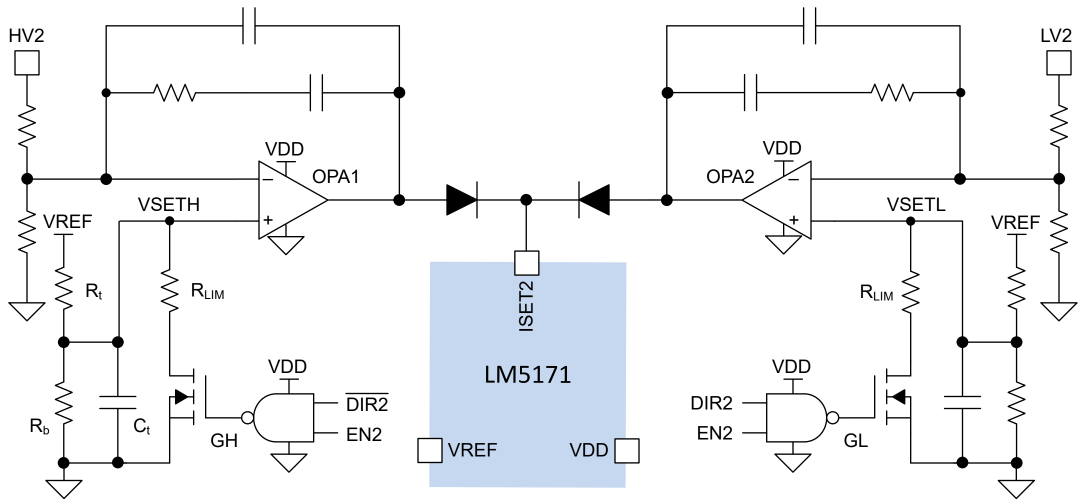

Figure 3-2. External Operational Amplifier Circuit Considering Soft Start and Loop Handover

Pull VSETL low when CH2 is shutdown (EN2 = low) or operating in boost mode (DIR2 = low). Similarly, pull VSETH low when CH2 is shutdown (EN2 = low) or operating in buck mode (DIR2 = high). The NAND gates fit this application well as shown in Figure 3-2.

When designing the resistor dividers, start from drawing 0.1mA from the VREF pin, R_b and R_t are found as,

$$R_b = \frac{VSETH}{0.1mA} \quad (1)$$

$$R_t = \frac{VREF - VSETH}{0.1mA} \quad (2)$$

The time constant of R_t, R_b and C_t determines the soft start time,

$$t_{SS} \approx 2(R_b||R_t) \times C_t \quad (3)$$

where $R_b||R_t$ is the parallel resistance of R_b and R_t,

$$R_b||R_t = \frac{R_b \times R_t}{R_b + R_t} \quad (4)$$

In this example, 2V reference voltage is selected. R_b = 15kΩ and R_t = 20kΩ are selected.

With the soft start time of 10ms, C_t is found as,

$$C_t = \frac{t_{SS}}{2(R_b||R_t)} = 583nF \quad (5)$$

A 560nF cap is selected.

2N7002 is selected to discharge C_t. R_{LIM} = 10Ω is selected to limit the peak current through the MOSFET.

4 Design of Additional OVP Circuit

In Figure 4-1, both the hiccup mode protection and latched protection are shown. Pull SS/DEMx pin low to achieve hiccup mode protection. Pull DT/SD pin low to shut down both channels and latch.

For the latched OVP, pull DT/SD below 0.5V to shut down both channels and latch. An open-drain comparator is a good fit here.

For the hiccup OVP, a small-signal MOSFET and a comparator are required. The SS/DEMx pins are multifunction pins. The SS/DEMx pins serve as ISETx soft start, and program each channel to operate in the DEM or FPWM. To create hysteresis, positive feedback is required. However, connecting the feedback resistor to SS/DEMx pin affects the soft start current and the DEM/FPWM control. A small-signal MOSFET is used so that the feedback resistor is not connected to SS/DEM2.

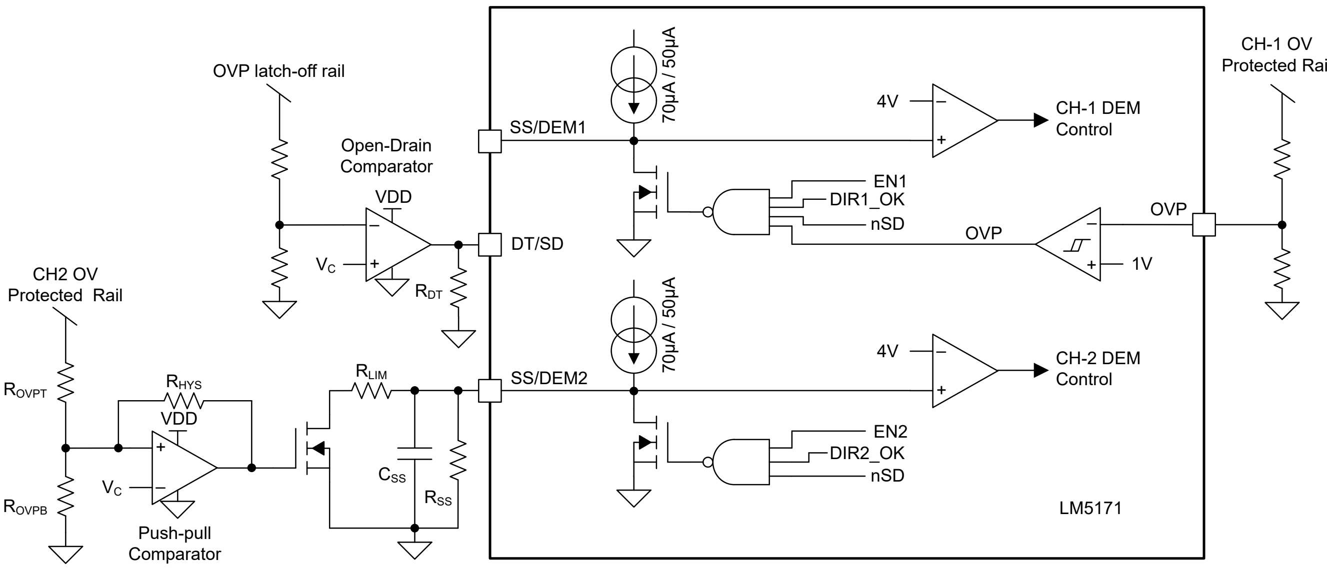

Figure 4-1. LM5171 with Additional OVP circuit

As shown in Figure 4-1, the hiccup OVP trigger voltage is,

$$V_{OVPH} = \frac{R_{OVPT} + (R_{OVPB} \| R_{HYS})}{R_{OVPB} \| R_{HYS}} \times V_C \quad (6)$$

The OVP voltage hysteresis is,

$$V_{HYS} = \frac{R_{OVPB} \| R_{OVPT}}{R_{HYS} + (R_{OVPB} \| R_{OVPT})} \times \frac{R_{OVPT} + (R_{OVPB} \| R_{HYS})}{R_{OVPB} \| R_{HYS}} \times VDD \quad (7)$$

Similar to selecting VSETH and VSETL, pay attention to the comparator common mode input voltage range when selecting V_C. With the supply of VDD, widely used comparators such as the LM393 series have a common mode input voltage range of 0V to VDD-2V over temperature. In this case, 1V to 2.5V is a reasonable range for V_C. Use a resistor divider from VREF pin to set V_C.

5 Common Settings

The peak current limit setting (IPK) and deadtime setting (DT/SD) are shared between the two channels.

When different peak current is required by CH1 and CH2, adjust the current sense resistor to get different peak current limit for each channel.

Both channels shut down and latch when DT/SD is pulled low.

6 Constant Current Operation with ISETx Clamping

CC/CV charging is a popular method of charging batteries. The average current mode control provides a simple way to achieve constant current operation: clamping the ISETx voltage.

Clamping ISETx with TLV431 is shown in Figure 6-1. The resistor divider sets the ISETx clamping voltage V_{clamp} to,

$$V_{clamp} = \frac{R1 + R2}{R2} \times 1.24V \tag{8}$$

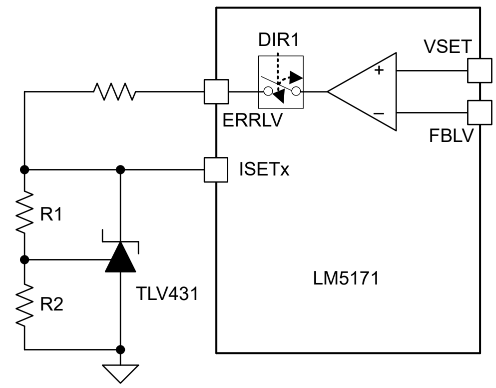

Figure 6-1. ISETx Clamping with TLV431

The charging current, battery voltage, ERRLV voltage and ISETx voltage are shown in Figure 6-2. In CC mode, the ISETx voltage is clamped to V_{clamp}. When the battery voltage reaches the target voltage, the converter enters CV mode. The output of the error amplifier drops and the ISETx voltage drops to less than V_{clamp}, the charging current is determined by the CV loop.

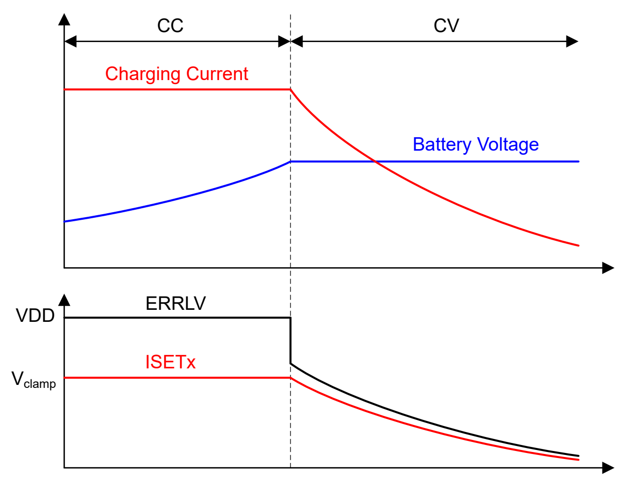

Figure 6-2. CCCV with ISETx Clamping

When an adjustable constant current is desired, clamp ISETx with an op amp as shown in Figure 6-3. The ISETx clamping voltage V_{clamp} follows $ISET_{input}$,

$$V_{clamp} = ISET_{input} \tag{9}$$

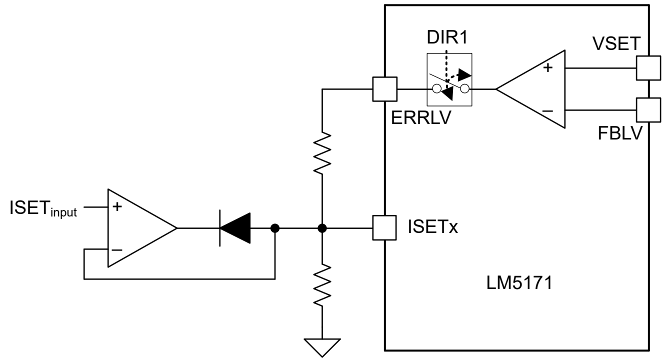

Figure 6-3. ISET Clamping with Op Amp

7 Summary

Two typical applications of operating the two channels of LM5171 independently are introduced,

- Two independent CC/CV chargers.
- A boost converter cascaded by a buck converter.

The circuit differences between the two channels of LM5171 are shown. The missing features of CH2 for a complete bidirectional converter are summarized. The design requirements of the external circuits are analyzed. Detailed block diagrams of the external circuit are shown, and some design examples are given.

8 References

- Texas Instruments, LM5171 Dual Channel Bidirectional Controller, datasheet.
- Texas Instruments, LM5171 Evaluation Module User's Guide, user's guide.
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