Application Report
SNVA846–August 2018

A Method to Improve LM5176 Overcurrent Protection Feature

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ABSTRACT

The LM5176 is a synchronous four-switch buck-boost DC/DC controller with wide input voltage range (4.2 V to 55 V). The device has three overcurrent protection methods including cycle-by-cycle current limit, operational hiccup current limit and operational averaging current limit. For cycle-by-cycle current limit, the buck mode has a valley current threshold of 80 mV typical at the sense pin, and the boost mode has a peak current threshold of 160 mV typical. For the hiccup mode, the gate drive pulse will keep low for 4000 oscillator cycles, if the inductor current exceeds the cycle-by-cycle current limit for consecutive 128 cycles. For the average current limit, the output current of LM5176 has a threshold voltage of 50 mV typical. The cycle by cycle current limit is mainly used to protect the inductor from saturation, the hiccup mode to limit the circuit dissipation in overloading condition, and the averaged current limit to protect against overloading and output short circuit condition. In many applications, the power converter is desired to operate as a constant voltage source in normal conditions, and it is expected to become a constant current source in the over loading condition, and it is required to operate in hiccup mode when short circuit happens to limit the power dissipation. However, because the LM5176 average current limit may prevent triggering the cycle by cycle peak current limit, the hiccup mode and average current limit cannot easily work together with.

In this article, the relationship between the hiccup mode and average current limit is analyzed; and a small external circuit is proposed to solve the incompatibility of hiccup mode and average current limit mode. Adding the external circuit, the LM5176 will enter into average current limit mode under overcurrent and into the hiccup mode when short circuit occurs. An experiment has been conducted to verify the effectiveness of this method.

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Trademarks

1 Introduction

When applying the appropriate voltage to the MODE pin of LM5176, the hiccup mode fault protection is enabled. In hiccup mode, the LM5176 shuts down after detecting cycle-by-cycle current limit for 128 consecutive cycles and the soft-start capacitor is discharged. After 4000 oscillator cycle clock, the soft-start capacitor is automatically released. The procedure will repeat until the fault is removed. As Figure 1 shows, when the LM5176 output is in short circuit condition, the inductor current and soft-start capacitor voltage will hiccup periodically.

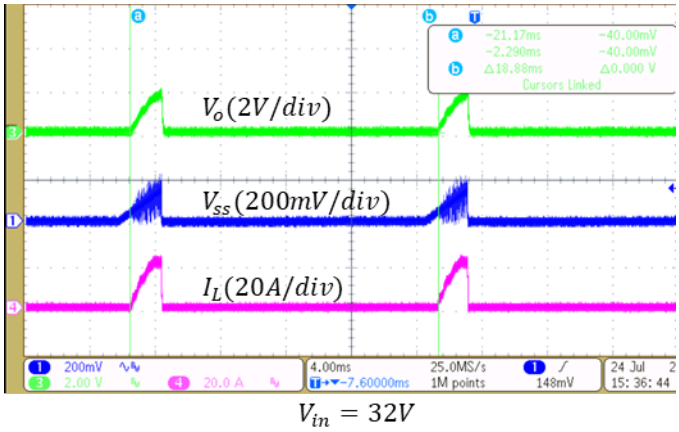

Figure 1. The Inductor Current and Output voltage Waveform in Hiccup Mode

If an additional current sense resistor is connected to ISEN+ and ISEN- pin, the average current limiting mode is enabled. If the voltage drop across the sense resistor is greater than 50 mV, the output current of LM5176 is regulated as a limited value. The target constant current is given by Equation 1.

$$I_{cl(average)} = \frac{50mV}{R_{sw}} \quad (1)$$

As Figure 2 shown, when LM5176 is overload, the output current will be regulated.

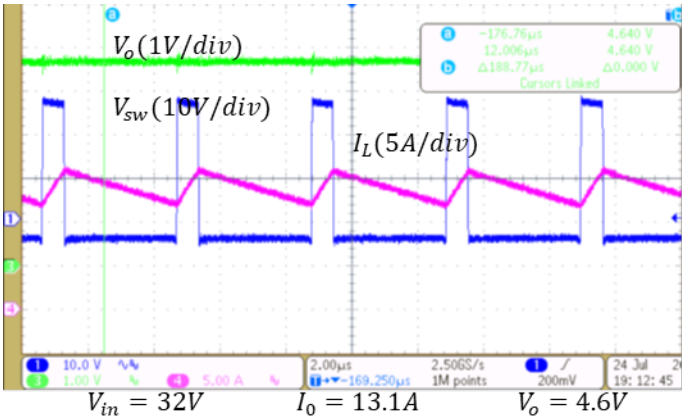

Figure 2. Average Current Limit Mode Waveform

2 The Relationship Between Hiccup Mode and Average Current Limit Mode

When the MODE pin connects to GND by a 93.1 kohm resistor and ISEN pins connect a shunt resistor R_{sen}, the hiccup mode and averaging current are enabled at the same time. But when LM5176 is overload or short circuit, LM5176 will not enter hiccup mode.

The cycle by cycle current limit thresholds of LM5176 are listed in Table 1. And we can get the current limit in buck and boost mode from Equation 1 and Equation 2 based on the current sense resistor R_{sw}.

Table 1. PWM Current Limit of LM5176

Voltage limit	Buck and boost limit	Min	Typ	Max
V_{cs}(buck)/mV	Buck current limit threshold	66	80	94
V_{cs}(boost)/mV	Boost current limit threshold	100	120	140

$$I_{buck} = \frac{V_{cs(buck)}}{R_{sw}} \tag{2}$$

$$I_{boost} = \frac{V_{cs(buck)}}{R_{sw}} \tag{3}$$

As Figure 3 show, R_{sw} is sensing resistor for switching and R_{sen} is sensing resistor for average current limit. Usually, the two resistor are the same value with R_{sw} =R_{sen}.

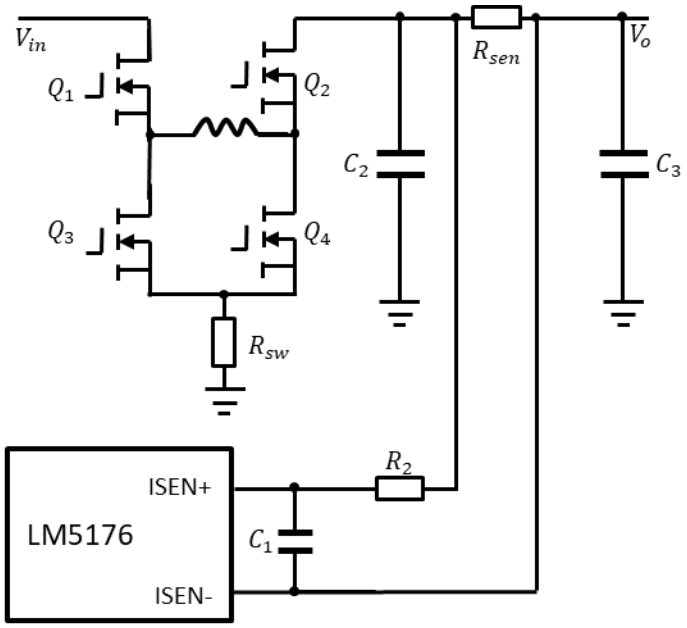

Figure 3. Schematic of LM5176

The cycle-by-cycle current limit in bulk mode is determined by the valley current of inductor. For the V_{in} = 32 V, I_{o_limit} = 13 A, R_{sw} = 4 mΩ, R_{sen} = 4 mΩ, f_s = 250 kHz and L = 4.7 uH, we can derivate the valley current of inductor.

The ripple current of inductor is as Equation 4

$$\Delta I_L = \frac{I_{o\_limit} R_o (1-D)}{f_s L} \quad (4)$$

The valley current of inductor is as Equation 5

$$I_{valley} = I_{o\_limit} - \frac{\Delta I_L}{2} \quad (5)$$

From the Equation 4 and Equation 5, the valley current of inductor with different load is as shown in Figure 4.

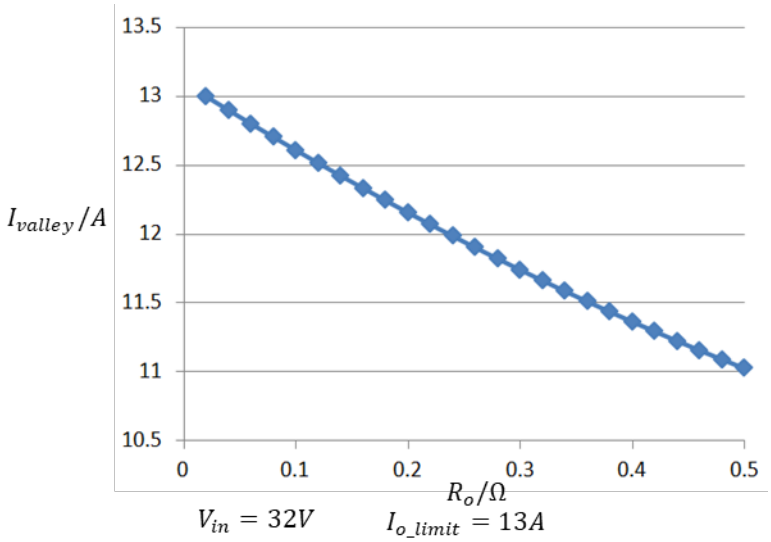

Figure 4. The Valley Current of Inductor with Different Load

From the above analysis, the valley current of inductor are below 13 A with average current limit mode enabled. However, the cycle-by-cycle current limit in buck mode with sense resistor R_{sen} 4 mohm is 20 A. The inductor current cannot reach the cycle-by-cycle limit in average current limit mode.

At the same time, we can observe the inductor valley current in an experiment. With V_{in} = 32 V and Io = 13 A, the inductor current are shown in Figure 5. It is apparent that the valley current of inductor is 12.8 A, which cannot reach the cycle-by-cycle current limit of 20 A.

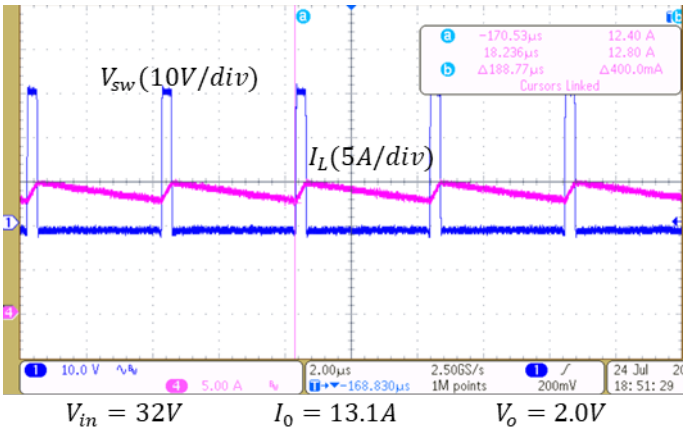

Figure 5. Waveform of LM5176 in Average Current Limit Mode

3 A Circuit to Improve LM5176 Short Circuit Protection

To enter into average current limit mode when overload and enter into hiccup mode when output short circuit, a new circuit has been designed as Figure 6 shown. A PMOS Q5 and two resistors R1, R4 has been added.

In normal working condition, V_o is high enough and V_{gs} of Q5 is higher than Q5 $V_{gs(th)}$. So Q5 will be turned on and doesn't affect the average current sensing. When overcurrent happens, the converter will work in average current limit condition.

When short circuit happens, the output voltage will start to decrease, which decreases V_{gs} . When V_{gs} is less than $V_{gs(th)}$, the P-FET will be turn off to cut off the average current feedback loop. The voltage between ISEN+ and ISEN- pin will be zero with average current limit mode disabled. Consequently, the valley current of inductor increases to reach the cycle-by-cycle current limit and LM5176 enters hiccup mode.

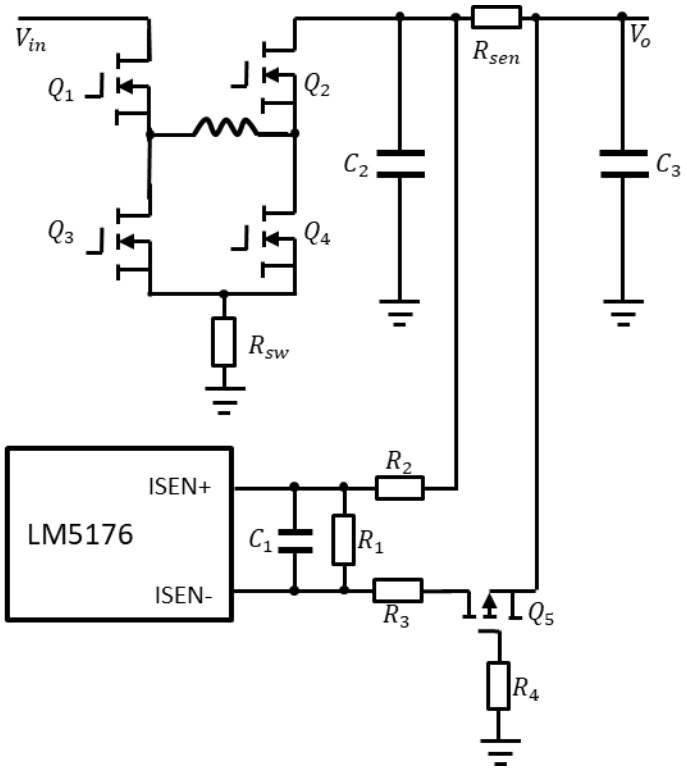

Figure 6. A New Circuit to Improve LM5176 Overcurrent Protection

3.1 Design Guideline

- • Because the hiccup trigger threshold is based on the $V_{gs(th)}$ of the PMOS, a signal P- FET with low $V_{gs(th)}$ is recommended. What's more, the drain-to-source voltage of MOSFET should be larger than output voltage. In this design, a P-FET with part number of AO3401 is used, which is rated at 30V V_{ds}, -2.5V $V_{gs(th)}$ and 4.2 A I_d.
- • For the gate drive resistor R_4, it can be 1 kohm. It should connect the gate to ground.
- • For the resistor R_1, it must be low enough to keep the voltage between ISEN+ and ISEN- zero. At the same time, R_1 should be far larger than R_2 resistor to set up the sensing voltage. A 2 kohm resistor is selected for R_1 with R_2 = R_3 = 100 ohm.

4 Experimental Result

An experiment has been conducted to verify the effectiveness of the proposed circuit in normal operation mode, overcurrent mode and short circuit mode.

Normal operation mode

When input voltage is 32 V with load current 10 A, the main waveform is as Figure 7 shown. The gate-to-source voltage of P-FET is 12 V with 12 V output voltage, which is higher than the threshold voltage. And the output current sensing path is connected to LM5176 with the P-FET on.

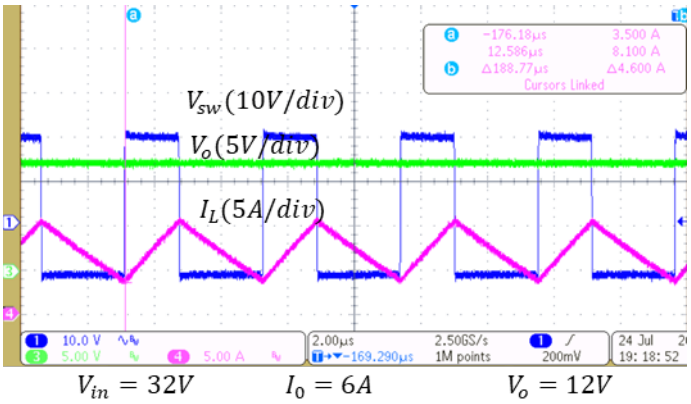

Figure 7. Waveform of Normal Operation Mode

When it is overloaded, the output current will be regulated to the limited level. As seen in Figure 8, the output current is12.6 A with the 12 A rated current. With the 3.3 V output voltage, the P-FET is on, keeping the average current sensing path connected.

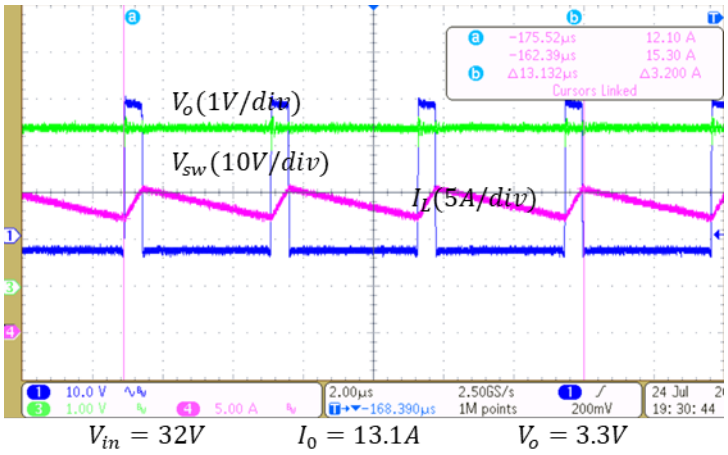

Figure 8. Waveform of LM 5176 in Overcurrent Stage

When short-circuit occurs, the output voltage is lower than the threshold voltage of P-FET, cutting off the feedback path of output current sensing. And the voltage of ISEN+ and ISEN- pin is 0 V with the hiccup mode enabled and the average current limit mode disabled. As Figure 9 shown, the output voltage hiccups periodically.

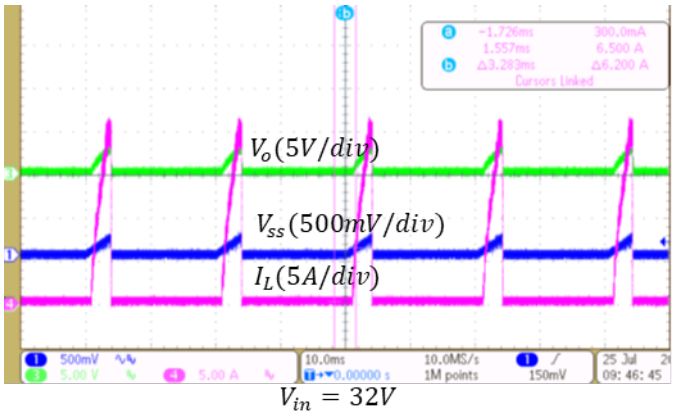

Figure 9. Waveform of LM5176 in Hiccup Mode

With the additional circuit, the output I-V curve of the LM5176 is changed as shown in Figure 10. In normal operating mode, the output voltage will be constant. As the load increasing to reach the overloading threshold, the output current will be limited as a constant current source. Once the overloading increase to become a short circuit condition, LM5176 enters hiccup mode.

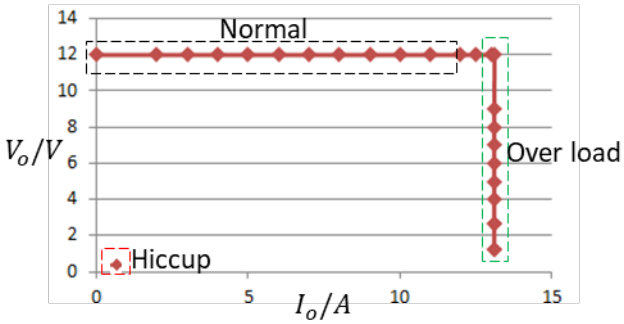

Figure 10. The Output Feature of LM5176 with the Additional Circuit

5 Conclusion

From the test results, the proposed circuit can get the average current limit and hiccup current limit function at the same time without affecting the normal operation.

6 References

- LM5176 Datasheet (SNVSAI1)
- LM5176 Wide-VIN Buck-Boost Controller EVM (SNVU547)

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