Current Limit Foldback Improves Short Circuit Protection in LM274X Family

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Introduction

This document discusses the function of the low side current limit used in the LM274X, and presents a simple method to enhance the short-circuit protection. Current limit is required to protect the power components from thermal stress which can reduce life span. Typically, high side current limit designs require an internal rising edge blanking time or external filter to avoid noise from falsely triggering the current limit comparator. The blanking time delays the current limit comparator from sensing the inductor current. This blanking time plus preventive shoot through dead time (designed into synchronous rectifier devices) determines the minimum on-time for switching regulators. In applications requiring DC-DC conversions from high input voltages to low output voltages, the buck converter must be able to operate down to very short on-time durations.

For space constrained applications, the typical switching frequency is in the order of 600 kHz to 3 MHz. These switching frequencies are selected to reduce the size of the storage charge elements (the inductor and capacitors). For example, an input voltage of 12V and an output voltage of 1.2V will require a buck duty cycle of 10%. Now, if the switching frequency is 1 MHz, the required on-time is 100 ns. Thus the application requires a current limit design that will allow for narrow on-time pulse to process the required output voltage.

Low Side Current Limit

The LM274X employs low side current limit which is implemented by sensing the voltage across the low side MOSFET while it is on, and allows for narrow duty cycle operation. Unlike a high-side MOSFET current sensing design, which limits the peaks of the inductor current, low side current sensing only limits the current during the converter off-time when inductor current is falling. Therefore in a typical current limit plot the valleys are normally well defined, but the peaks are variable according to the duty cycle. During current limit mode the peak inductor current can exceed the current limit threshold, as shown in *Figure 1*.

When the inductor current exceeds the current limit threshold, the high side MOSFET on-pulse is skipped until the inductor current falls below the current limit threshold, and then it resumes normal on-time pulses.

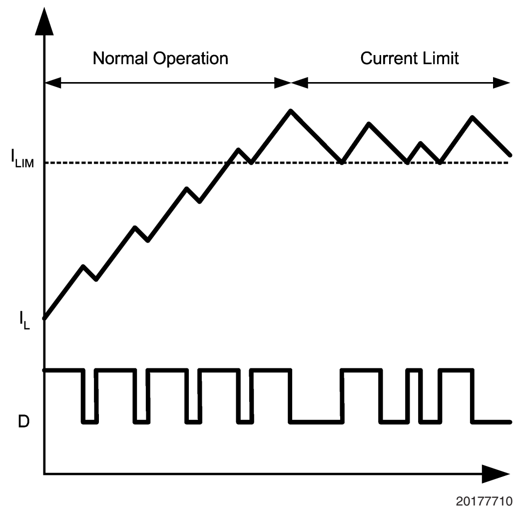

FIGURE 1. Current Limit Threshold

Output Short Circuit

In a typical output short circuit to ground event, the input differential across the error amplifier (EA) will try to force maximum duty cycle pulses. This response will increase the average inductor current every cycle until the inductor current exceeds the current limit threshold. In order to minimize the time period in which peak inductor current exceeds the current limit threshold, the LM274X discharges the soft-start (SS) capacitor. Once the SS pin voltage (V_{SS}) is lower than the reference voltage (V_{REF}), V_{SS} will take control of the non-inverting input of the EA and will reduce the duty cycle during this condition. See Figure 2 for a simplified block diagram.

Output Short Circuit (Continued)

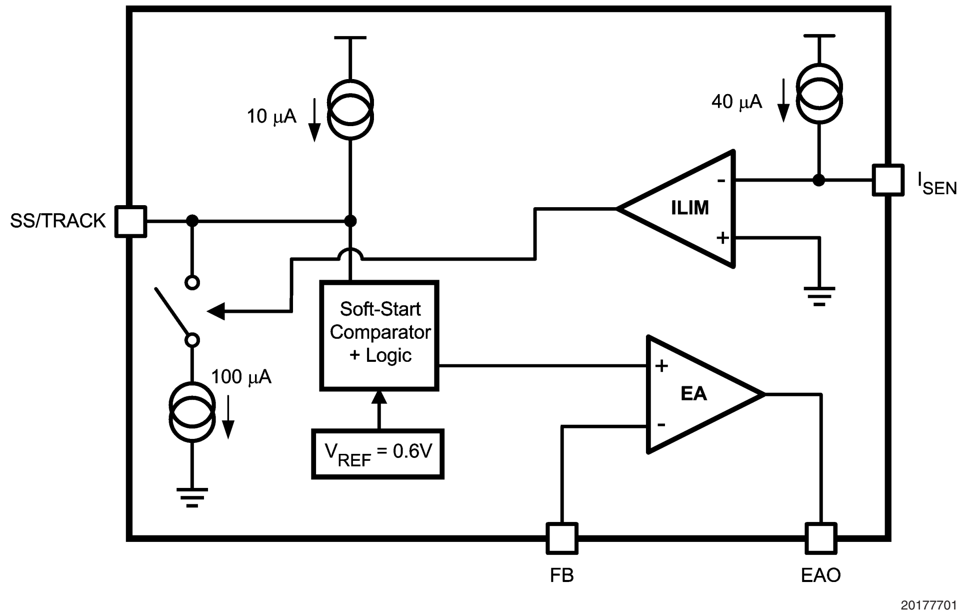

FIGURE 2. Error Amplifier and Current Limit Block Diagram

By definition a short circuit is a low impedance path established between two points in a circuit. Peak currents are higher with low impedance than with a high impedance output short circuit to ground, because the condition of $V_{SS} > V_{FB}$ can occur. This means that the LM274X may still switch at maximum duty cycle. The worst case short circuit peak current can be approximated by the following equation:

$$I_{PKC} = I_{LIM} + (T_S \times D_{MAX}) \times \frac{V_{IN} - V_{OUT}}{L_O}$$

where D_{MAX} = 73% at 300 kHz at 25˚C.

Now for an example calculation: V_{IN} = 12V, V_{OUT} = 0V, L_O = .68µH, and I_{LIM} = 15A. The peak inductor current (I_{PKC}) results in 57A. The measurement results shown in *Figure 3* matches with the calculated values above. If the inductor saturates, the peak inductor current will increase. The following section explains how we will reduce the peak current during low impedance short circuit events.

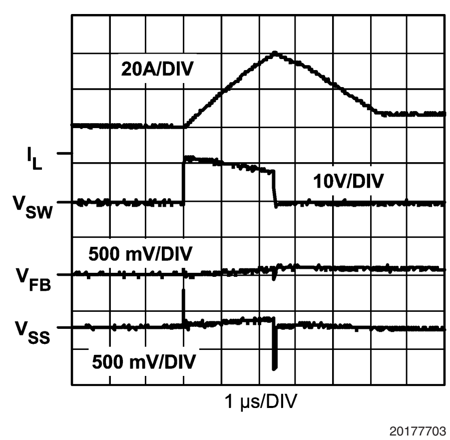

FIGURE 3. Low Impedance Short

Enhanced Short-Circuit Protection

To enhance the short circuit protection, connecting a single resistor (R_{CLF}) from I_{SEN} to V_{OUT}, as shown in *Figure 4*, decreases the DC current limit level during a short circuit from output to ground. The Design Procedure section will provide selection guidelines for the foldback current limit (P_{LIM}), R_{CLF}, and the current limit resistor (R4).

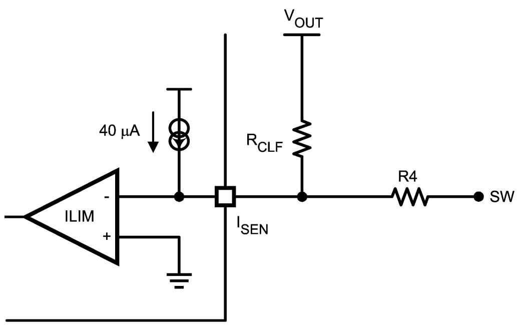

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FIGURE 4. Location of the Current Limit Foldback Resistor

Design Procedure

Given the following application parameters: V_{IN}, V_{OUT}, bottom FET $R_{DS(ON)}$, I_{LIM}.

Select the percentage of current limit foldback (P_{LIM}):

$$P_{LIM} = I_{LIM} \times P$$

where P is a ratio between 0 and 1.

Obtain R4 with the following equation:

$$R4 = \frac{P_{LIM} \times R_{DS(ON)}}{I_{SEN}}$$

where I_{SEN} = 40 µA (typ).

If the input voltage goes above 9.5V the following criterion must be satisfied.

$$R4 \geq \frac{V_{IN} - 9.5V}{10\ mA}$$

For example: V_{INmax} = 13.2V the minimum R4 value is 370Ω.

The equation for calculating R_{CLF} value is:

$$R_{CLF} = \frac{R4 \times V_{OUT}}{(I_{LIM} \times R_{DS(ON)}) - (I_{SEN} \times R4)}$$

Use the hot $R_{DS(ON)}$ value found in the manufacturer's datasheet.

With new resistance value for R4 and the introduction of R_{CLF}, we can verify the reduction in peak current during an output short circuit to ground. Thus, assuming the inductor does not saturate, use the following equation to calculate peak current during an output short circuit to ground.

$$I_{PKC} = P_{LIM} + (T_S \times D_{MAX}) \times \frac{V_{IN} - V_{OUT}}{L_O}$$

Under the same condition as the first calculated example: D_{MAX} = 73% at 300 kHz at 25˚C, V_{IN} = 12V, V_{OUT} = 0V, L_O = .68 µH, and P_{LIM} = 5A. I_{PKC} results in 47A. *Figure 5* shows the measured inductor current, which matches with the calculated value above. In this case we have reduced the peak inductor current by 10A.

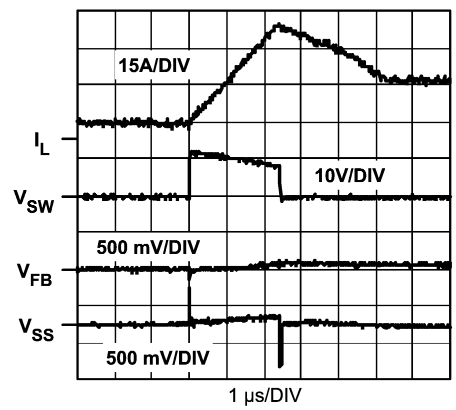

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FIGURE 5. Low Impedance Short

In summary the LM274X family can provide narrow duty cycle operation, and by introducing a single resistor the peak currents can be reduced when the output of the regulator is short circuit to ground.

Notes

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