

Input Capacitor Selection Guide for MP2130

Application Note

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ABSTRACT

The root cause of voltage overshoot on the input pin during soft-stop and how to select the input capacitor are introduced in this application note. Under light-load and large-output-capacitor condition, the buck IC operates in soft-stop mode and can behave as an undesirable boost circuit. This application note describes how to select an appropriate input capacitor to absorb the energy from regulated output capacitors to prevent input overvoltage. It is also useful for other Buck parts with soft-stop function.

Input Capacitor Selection Guide for MP2130

The MP2130 is a monolithic step-down switch-mode converter with built-in internal power MOSFETs. It achieves a 3.5A continuous output current from a 2.7V-to-6V input voltage with excellent load and line regulation. The MP2130 has a built-in soft-start that ramps up the output voltage at a controlled slew rate, avoiding overshoot at startup. When disabled, the MP2130 ramps down the internal reference thus linearly discharging the output. The soft-stop time is typically about 1ms.

During soft-stop, the low-side internal MOSFET switches to control the slew rate of the output voltage that follows the internal reference. Under light-load and large-output-capacitor condition, the high-side MOSFET is almost off during the soft-stop procedure. The energy stored in the output capacitor transfers to the input capacitor through the inductor. The topology changes to a boost converter with the high-side MOSFET acting as a parasitic diode, as shown in Figure 1. The boost voltage causes an overshoot on the input capacitor; sometimes this overshoot exceeds the absolute maximum voltage (V_{ABS}) of the input pin and can damage the IC. To prevent this, increase the input capacitor value to absorb this energy as per this input capacitor selection guide.

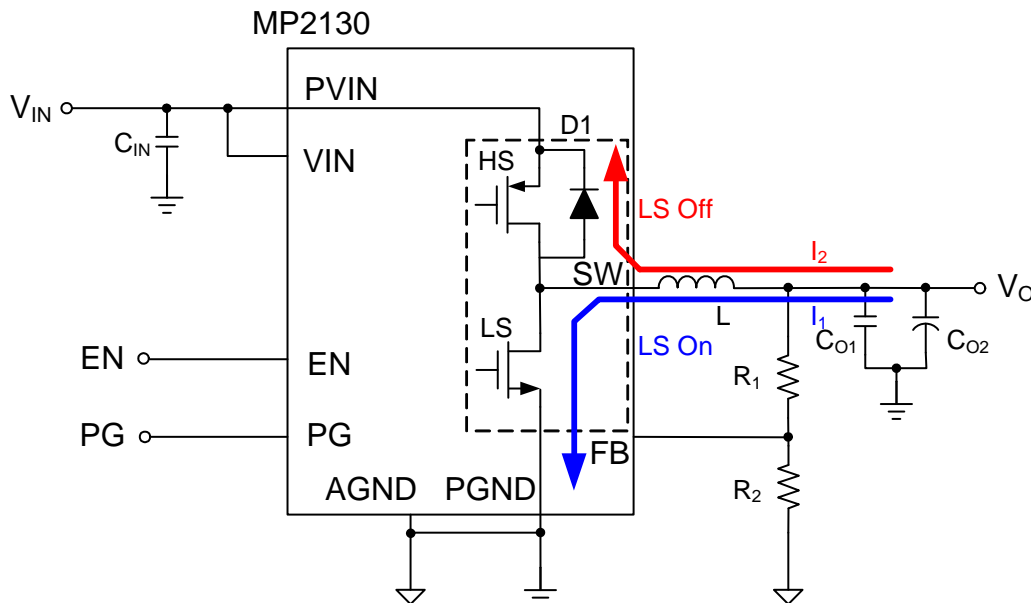


Figure 1: Buck Topology Changes to Boost at Soft-Stop

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INTRODUCTION

Some special applications or the test processes need the output voltage to fall at a regulated rate for a fixed time being disabled: This feature is called soft-stop. Usually, this function causes the output voltage to fall smoothly, analogous to the soft-start. Care must be taken at light load and large output capacitor condition as there may be an overshoot voltage on the input pin caused by this phenomena. To protect the IC from being damaged by this overshoot, the input capacitor needs to be increased to absorb this overshoot.

This application note describes the source of overshoots, and provides a method to select an appropriate input capacitor.

WHY OVERSHOOT VOLTAGE OCCURS

Figure 1 shows the topology change during soft-stop. During soft-stop, the low-side internal MOSFET (LS-FET) switches to control the slew rate of the output voltage, which follows the internal reference. Under light-load and large output capacitor condition, the high-side MOSFET remains on for only a short portion of the soft-stop period. When the LS-FET switches, the inductor current starts flowing from the output capacitor to the SW pin. The output capacitors C_{O1} and C_{O2} , the inductor L , the LS-FET, the parasitic diode $D1$, and input capacitor C_{IN} become a boost circuit. This can cause the voltage on the VIN pin to rise rapidly and overshoot, as shown in Figure 2.

To protect the IC from overvoltage damage, use a large input capacitor to absorb overshoot.

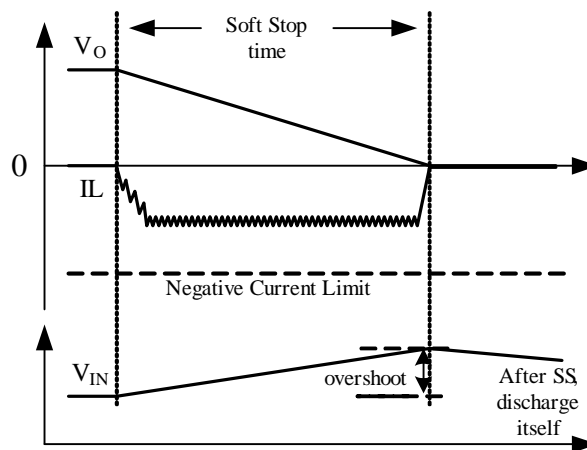


Figure 2: Overshoot Voltage on VIN during Soft Stop Time

CHOOSING AN APPROPRIATE INPUT CAPACITOR

a. LS-FET Current Cannot Exceed the Negative Current Limit

To simplify the analysis, use the average value to calculate the inductor current. If the negative inductor current is less than negative current limit, then the output voltage can be regulated from the nominal value to 0V within the fixed soft-stop period. You can refer to Figure 2. During soft-stop, estimate the lowest negative inductor current using the equation below:

$$I_{NEG} = \frac{C_O \times V_O}{t_{SStop}} \tag{1}$$

Where I_{Neg} is most negative inductor current,
 C_O is the output capacitor,
 V_O is the output voltage,
 t_{SStop} is the soft stop time.

Under this circumstance, all energy stored in the output capacitor transfers to the input capacitor. Consider the conduction loss on inductor, low-side MOSFET (LS-FET) and parasitic diode, estimate 80% transfer efficiency of boost converter. Therefore the transferred energy can be calculated by below equation:

$$W_{Boost} = 0.5 \cdot C_O \times V_O^2 \times 0.8 \tag{2}$$

Where W_{Boost} is the transferred energy.

To absorb this energy and protect the IC, the current input voltage plus the overshoot voltage cannot exceed V_{ABS} on the input pin. The required minimum input capacitor can be calculated below:

$$C_{IN(Min)} = \frac{2 \cdot W_{Boost}}{V_{ABS}^2 - V_{IN}^2} \tag{3}$$

Where $C_{IN(Min)}$ is the minimum input capacitor, and V_{ABS} is the absolute maximum value of input pin.

b. LS Current Exceeding the Negative Current Limit

Sometimes the stored energy in the output capacitor is very large (when the output voltage is high, or the output capacitance is large, or both). The IC can not regulate the output voltage using the internal reference during soft stop because the negative current limit protecting the LS-FET prevents high-current conduction. In this situation, the output voltage does not drop to zero during soft-stop and the inductor current is limited by the negative current limit of the LS-FET, as shown in Figure 3.

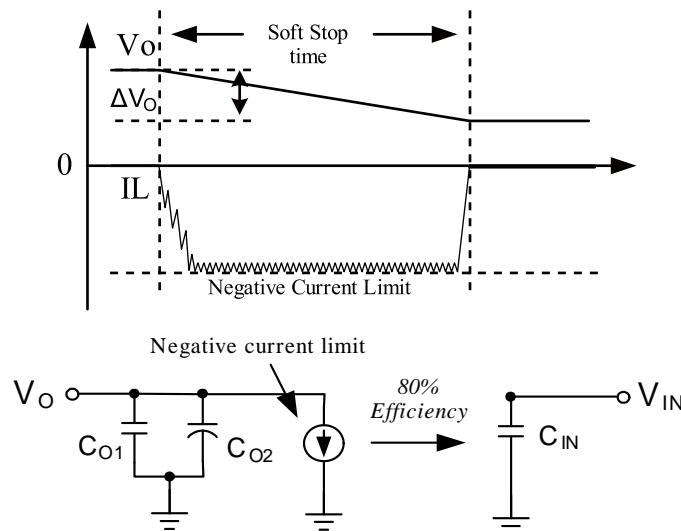


Figure 3: Simplified Transfer Mode at Negative Current Limit

The output capacitor discharges at the current limit. If the output capacitor exceeds $C_{O(Max)}$, the inductor current is limited to:

$$C_{O(Max)} = \frac{I_{Neg_Lim} \times t_{SStop}}{V_O} \quad (4)$$

Where $C_{O(Max)}$ is the boundary value that the inductor current at the negative limit;
 I_{Neg_Lim} is the negative current limit of the LS-FET.

Figure 3 also shows the simplified transfer mode if the current reaches the negative current limit. In this mode, a current sink of equal value to the negative current limit discharges the output capacitor. Considering the conduction loss on the inductor, the LS-FET, and the parasitic diode, estimate an 80% boost-converter transfer efficiency. Then the transferred energy can be calculated below:

$$W_{Boost} = 0.5 \cdot C_O \times \left[V_O^2 - \left(V_O - \frac{I_{Neg_Lim} \times t_{SStop}}{C_O} \right)^2 \right] \times 0.8 \quad (5)$$

The required minimum input capacitor now can be calculated:

$$C_{IN(Min)} = \frac{2 \cdot W_{Boost}}{V_{ABS}^2 - V_{IN}^2} \quad (6)$$

EXAMPLE DESIGN

The following is an example input-capacitor calculation using the detailed design procedure described previously for the MP2130. The MP2130 is a monolithic, step-down, switch-mode converter with built-in internal power MOSFETs. It achieves 3.5A continuous output current from a 2.7V-to-6V input voltage. It has excellent load and line regulation. The calculations are based on the following parameters:

- $V_{ABS} = 6.5V$
- $I_{Neg_Lim} = 2.5A$
- $t_{SStop} = 1ms$
- $V_{IN} = 4.5V$
- $V_O = 3.3V$
- $L = 1\mu H$
- $C_O = 10\mu F + 470\mu F$ E-Cap.

First, the C_{O_Max} was calculated based on Equation (4):

$$C_{O(Max)} = \frac{I_{Neg_Lim} \times t_{SStop}}{V_O} \approx 750\mu F$$

In this example, C_O is smaller than C_{O_Max} and the inductor current will not exceed the negative current limit. Calculate the input capacitor value using equations (2) and (3), or equations (5) and (6). The minimum required input capacitor is then:

$$W_{Boost} = 0.5 \cdot C_O \times V_O^2 \times 0.8 = 2090\mu J$$

$$C_{IN(Min)} = \frac{2 \cdot W_{Boost}}{V_{ABS}^2 - V_{IN}^2} = 190\mu F$$

Therefore the minimum input capacitor should be larger than 190µF, and preferably use a 330µF capacitor for this example. Below is the curve of the minimum input capacitance vs. the output capacitance for this example.

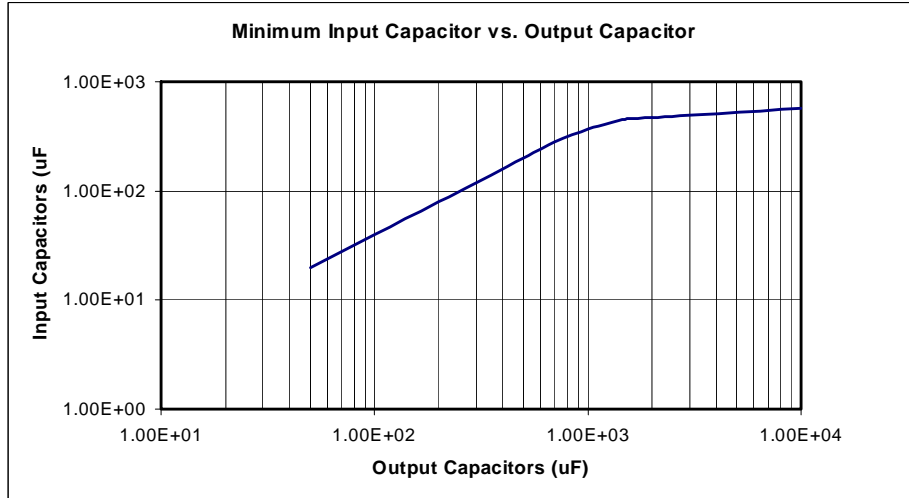


Figure 4: Minimum Input Capacitor vs. Output Capacitor

CONCLUSION

The root cause of input voltage overshoot during soft stop and how to select the input capacitor are introduced in this application note. Under light load conditions with a large output capacitor, the soft-stop mode may act as a boost circuit. This application note describes how to select an appropriate input capacitor value to absorb the energy from regulated output capacitors. The design example and procedure also help the engineers develop simple solutions based on different output capacitor values.

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