



Elisabetta Mahmutovic, Stefan Schauer

ABSTRACT

During the definition of a switched mode power supply (SMPS) the most typical application scenario is the steady state to calculate and define the operation parameters and the configuration, for example, the inductor, output capacitors, operation mode. But before the DCDC converter reaches its first steady state operation point it needs to power up. Without taking certain considerations the high inrush current to charge up the output capacitor would typically trigger the overcurrent limit and force the system to restart. This can lead to a system which could even not start up if the output capacitor fully discharge till the next restart cycle is initiated.

The inrush current needs to be split into the current which flows into the input capacitor and the current which is going to the output side of the SMPS. The output side then again splits into the current to charge the output capacitor and the 2nd part which is required for the application. Esp. due to the relative high output capacitors typically required, a high current is flowing into them during the charge up phase until the voltage has reached the required output voltage level.

To overcome this a so called soft-start circuit should be utilized. In below example the [LM5155](#) will be used but this will apply to most SMPS (Switched Mode Power Supply) devices.

The report will discuss several aspects on how to define the soft-start time.

Table of Contents

1 Overview	2
2 Design Considerations	3
3 Soft-Start Time Calculation Considerations	4
4 Soft-Start Time Within Different Topologies	5
5 Fixing Soft-Start Issue	7
6 Summary	7
7 References	7

List of Figures

Figure 1-1. Soft-start Timing.....	2
Figure 4-1. PNP Bipolar Transistor Between the Soft Start Pin and the COMP Pin.....	6
Figure 4-2. Secondary Side Soft Start on Flyback.....	6

Trademarks

All trademarks are the property of their respective owners.

1 Overview

At the turn on of the SMPS, both the input and the output capacitors need to be charged. While the input capacitor is charged directly from the input supply, the output capacitors are charged through the DC-DC converter. The current needed to charge the capacitors at the output might be much higher than the maximum load current and therefore the overcurrent protection might be triggered causing the system to restart or shut-down.

The overcurrent condition and consequent restart will stress the circuit as the maximum allowable current is flowing through the power stage components. In addition, if the controller is enforcing a dead time before restarting, this might cause the discharge of the output capacitor leading to an endless re-start loop.

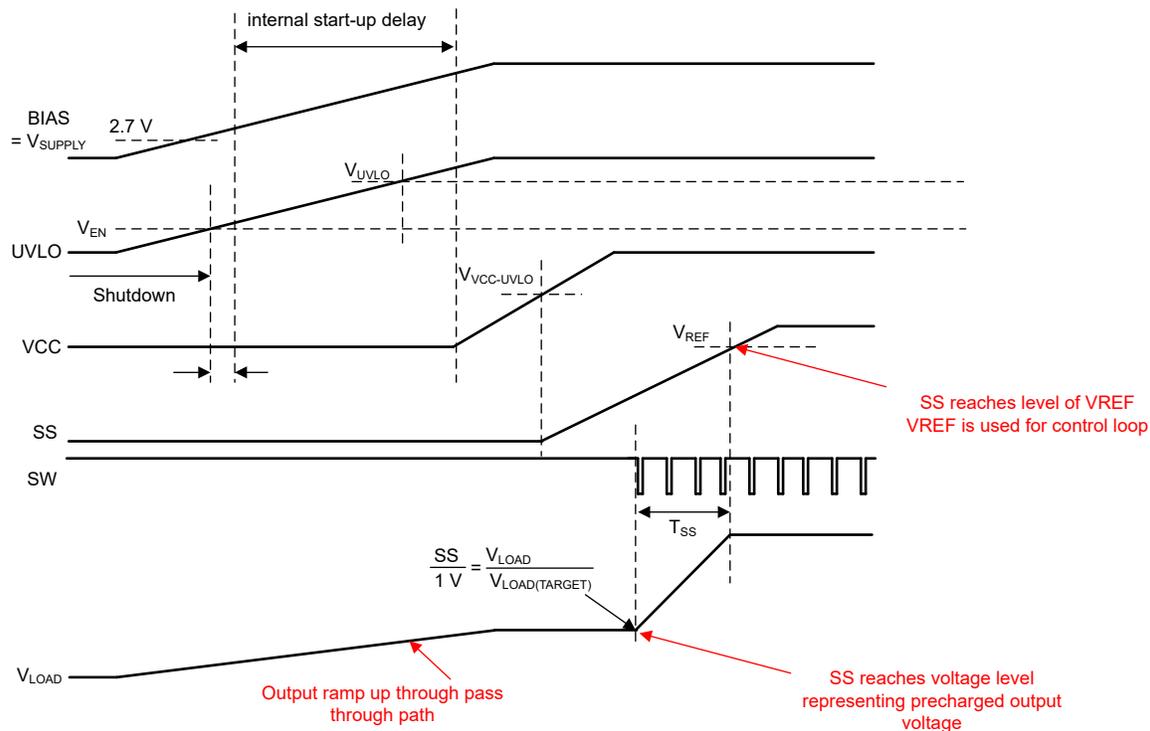


Figure 1-1. Soft-start Timing

Typically the soft-start mechanism allows to slowly ramp up the output voltage until the regulation target is achieved. This allows the output capacitors to charge with a defined current. In the case of the [LM5155](#) the reference signal is modified by the voltage level of a charged capacitor (soft-start cap) connected to the soft-start (SS) pin of the device. During the start phase this capacitor is charged by a constant current source and as long as this voltage is below the internal reference voltage, the voltage on the SS capacitor is used for the adjustment of the output voltage. The start up time is defined via the value of the capacitor connected to the SS pin.

One mechanism is to limit the duty cycle of the MOSFET in order to limit the maximum peak current in the system and consequently avoid a big inrush current and overshoot of the output voltage. Thanks to the soft-start, the MOSFET is not starting at the maximum possible pulse width.

2 Design Considerations

To define an appropriate soft-start time to ramp up the output voltage to the required level some aspects of the application need to be considered:

- Maximum output current
- This is the maximum load current which the converter can supply without getting into any limitation, either current limit or device parameter limits. Device parameter limits must never be violated and a well-defined margin need to be considered.
- Output capacitance and the ESR of the output capacitors. The capacitance plays a significant role as it dictates the value of the inrush current, together with the target value of the output voltage. This current is basically only limited by the ESR of the capacitors. (In most cases the ESR can be neglected as, especially for ceramic capacitors, it is quite low.)
- Behavior of the load during the startup phase
- Beside the inrush current of the output capacitor also the load on the SMPS can contribute to the current during the start phase. This needs to be evaluated and considered individually, for example, an ohmic load can ramp linear while a Processor or uController can only start at a certain voltage level or even after the power supply has stabilized and, in this case, might not need to be considered for the soft-start time.

3 Soft-Start Time Calculation Considerations

The soft-start ramp time can be calculated with [Equation 1](#)

$$C*U = I*t \tag{1}$$

Reordered to t_{SS} gives [Equation 2](#):

Where:

$$t_{ss} = \frac{C_{OUT} * U_{SS_Step}}{I_{SS_Ramp}} \tag{2}$$

U_{ss_step} : Softstart voltage ramp = *Expected voltage after Softstart - Precharge voltage*

Expected voltage after Soft-start: typically V_{OUT}

Precharge voltage: For Boost the input voltage for most other topologies 0 V

C_{out} : total output capacitance

I_{ss_ramp} : current available for the charging of the output capacitors during soft-start. If there is a contribution of the target load during the soft-start time this needs to be subtracted first. For example, if the SMPS supplied a circuit which only gets enabled after power good is signaling the power up has finished, the load current can be fully used for the startup. In case of an ohmic load which is connected all the time only the Delta between target load current and max load current can be used for that. But in this case still some margin can be used to avoid the system triggers overcurrent

3.1 Soft-Start Capacitor Selection for the LM5155x

At start-up of the [LM5155](#), the internal 10- μ A soft-start current source (I_{SS}) turns on 50 μ s after the VCC voltage exceeds the 2.85-VCC UV threshold, or if the VCC voltage is greater than 4.5 V, whichever comes first. The soft-start current gradually increases the voltage on an external soft-start capacitor connected to the SS pin. The SS pin is pulled down to ground and the capacitor on the SS pin is discharged by an internal switch if the VCC is less than VCC UVLO threshold, the UVLO is less than the UVLO threshold, during hiccup mode off-time or during thermal shutdown.

The soft-start capacitor is used to minimize and overshoot on the load voltage during the start-up of the regulator. [Equation 3](#) is used to calculate the minimum recommended soft-start capacitor value.

$$C_{SS} > \frac{10\mu A \times V_{LOAD} \times C_{OUT}}{I_{LOAD}} \tag{3}$$

In a secondary side isolated Flyback, the soft-start mechanism is taking over right at the start up, when the optocoupler is not yet conducting (meaning $V_{LOAD} <$ approximately 1.5 V).

4 Soft-Start Time Within Different Topologies

4.1 Buck Topology

(The [LM5155](#) is a boost controller but for completeness this is shown here as well)

Buck will start at 0 V:

The slow-start time needs to be longer (slower) than the time constant of the output LC filter. This time constraint can be expressed as described in [Equation 4](#)

$$t_S \geq 2\pi\sqrt{L_{OUT} * C_{OUT}} \quad (4)$$

4.2 Boost Topology

Will start with output voltage = VIN as this is the pass-through through the inductor

SS will charge up till the voltage reaches the voltage level representing the already precharged output (=Input voltage level) and then start switching and charging up the output with the ramp of the soft-start.

In the boost topology, the soft-start time (t_{SS}) varies with the input supply voltage. The soft-start time in the boost topology is calculated as shown in [Equation 5](#).

$$t_{SS} = \frac{C_{SS}}{I_{SS}} \times \left(1 - \frac{V_{SUPPLY}}{V_{LOAD}}\right) \quad (5)$$

4.3 Sepic Topology

The SEPIC converter output voltage will start at 0 V – therefore different equations are given for boost and SEPIC.

In the SEPIC topology, the soft-start time (t_{SS}) is calculated as [Equation 6](#).

$$t_{SS} = \frac{C_{SS}}{I_{SS}} \quad (6)$$

4.4 Flyback Topologies

This section includes the different flyback topologies and their soft-start implementation. A capacitor on the soft-start pin of the IC is always necessary and in addition, according to which topology has been selected, a second mechanism is required.

4.4.1 PSR Flyback: Bipolar Transistor as Pull Down for COMP Pin

In a Primary Side Regulated Flyback (PSR) two soft-start mechanisms are necessary:

- The capacitor on the soft start pin
- The PNP bipolar transistor between the soft start pin and the COMP pin as shown in [Figure 4-1](#)

The PNP bipolar transistor is necessary to limit the maximum peak current that can be delivered during start up and therefore avoid an overshoot of the output voltage.

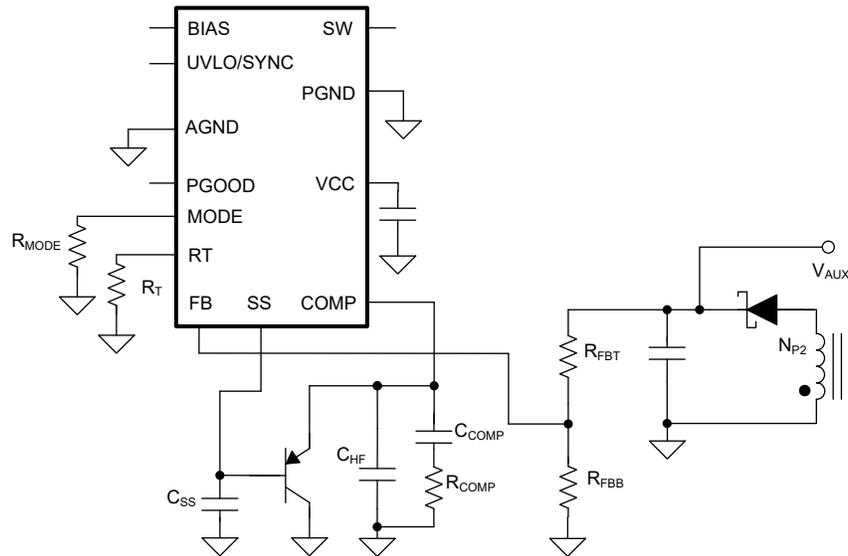


Figure 4-1. PNP Bipolar Transistor Between the Soft Start Pin and the COMP Pin

4.4.2 Secondary Side Soft-Start Components

In the case of a secondary side regulated isolated flyback, see [Figure 4-2](#), a mechanism on the secondary side is needed as well in addition to the capacitor on the SS pin and it comprehends:

- One capacitor ($C_{SS,Sec}$)
- One resistor to slowly keep the capacitor charged during operation ($R_{SS,Sec}$)
- Two diodes: one to allow charging the cap and one to allow its discharge (D_{DIS} , dual package)
- One resistor to determine the RC time constant ($R_{OPTO,Diode}$, in series with optocoupler)

Until the optocoupler is not conducting (V_{out} from 0 V to around 1.5 V), the cap on the SS pin is limiting the peak current in the system. As soon as the optocoupler starts conducting then the soft start on the secondary side takes over. In this case the capacitor on the secondary side gets charged through the bottom diode and discharged thanks to the upper diode in order to be ready for a successive soft start event if needed.

The RC time constant is given by the capacitor on the secondary side itself ($C_{SS,Sec}$) and the resistor in series with the optocoupler ($R_{OPTO,Diode}$).

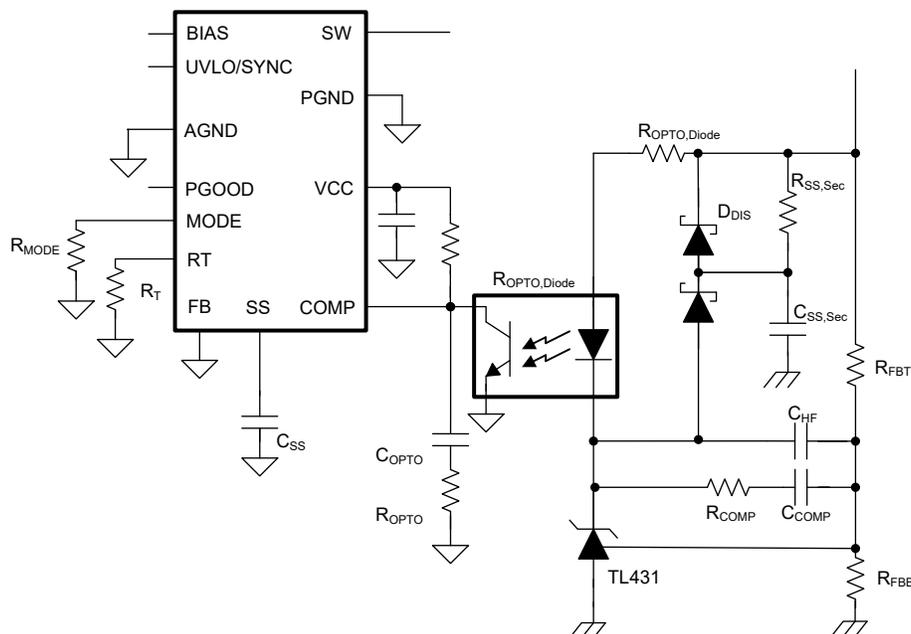


Figure 4-2. Secondary Side Soft Start on Flyback

Once current starts to flow through the opto, the time constant formed by the secondary SS cap and the resistance that is in series with the opto will control the remainder of the startup time. This is because these two elements then control the feedback current through the opto. Once the output voltage reaches the final value, the TL431 takes over and controls the feedback current through the opto. At this point, the resistor connected from the secondary SS cap to V_{OUT} continues to charge the secondary SS cap so that it can no longer interfere with the loop. This resistance is usually very large, so that it does not affect the startup time.

When this circuit is not used, like in the PMP22151 for example, the primary SS cap will completely control the start up time. However, this often results in over-shoot of the output voltage during startup. (This is the main reason to use the secondary SS circuit.) The over-shoot happens because the TL431 amplifier is in saturation while the primary SS is in control of the loop.

5 Fixing Soft-Start Issue

When the SMPS does not start up as expected, the following needs to be checked:

- A very large output capacitance can cause the converter to hit the overcurrent limit during startup; the hiccup auto-restart process continues indefinitely
- Change the sense resistor to allow a higher peak current (and adapt the circuit for the higher current: MOSFET, inductor and rectifier diode)
- Reduce the output capacitance (consider higher output ripple)
- Increase the soft-start time
- In general, we know that the converter might have hit overcurrent protection because COMP pin or CS pin is hitting the overcurrent threshold, but V_{OUT} is below the regulation point

6 Summary

The configuration of the correct Soft Start time is critical and important for a switch mode power supply. In this report, the principal and the selection of the Soft Start components and circuits have been discussed and possible circuit designs were described.

7 References

1. Texas Instruments, [LM5177 80-V Wide VIN Bidirectional 4-Switch Buck-Boost Controller](#), data sheet.
2. Texas Instruments, [LM5177 Buck-Boost Controller Evaluation Module](#), user's guide.
3. Texas Instruments, [TL431 Precision Programmable Reference](#), data sheet.
4. Texas Instruments, [Power Tips: A simple circuit to implement smooth soft start for an isolated converter](#).
5. Texas Instruments, [LM5155EVM-BST](#), user's guide.
6. Texas Instruments, [LM5155EVM-FLY](#), user's guide.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](https://www.ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2023, Texas Instruments Incorporated