Application Report
SLVA553–January 2013

Extending the Soft Start Time in the TPS63010 Buck-Boost Converter

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ABSTRACT

In battery-powered equipment, extending the soft start time can be crucial to a glitch-free start up. Especially toward the end of a battery's life, the voltage drop and increasing impedance of the battery from excessive inrush current into the power supply can be a problem. This application report demonstrates a simple circuit that extends the soft start time and reduces the inrush current on the TPS63010 buck-boost converter.

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1 TPS63010 Soft Start Operation

The TPS63010 has a very simple soft start process. It limits the average input current to an internally set limit, which varies based on the level of the output voltage. The input current limit increases as the output voltage rises up. When the output voltage is at 0 V, the current limit is approximately 400 mA. This reduces the power dissipated into a short circuit on the output, protecting the system, TPS63010, and input bus from possible damage due to sourcing excessive output current into a short. Since there is no timer implemented, the soft start time depends mainly on the total capacitance on the output as well as the load current during start up. Such a start up routine, though simple, may cause issues in some systems that require a longer soft start time.

2 Extending the Soft Start Time

The technique used in this application report to extend the soft start time and decrease the inrush current adds a feedforward capacitor connected through a diode to the FB pin. The diode provides isolation of the capacitor, so that it affects neither the steady state operation nor the dynamic response of the converter. Increasing the input capacitance and/or decreasing the output capacitance also reduces the magnitude and/or duration of the inrush current drawn from the input bus during start up. Decreasing the output capacitance decreases the amount of charge required from the input bus to charge the output capacitance, while increasing the input capacitance increases the amount of stored charge that can be provided to the output during start up. Storing more charge with more input capacitance reduces the peak charge required from the input bus during start up. However, adjusting these capacitor values does not increase the soft start time and affects other system characteristics, such as input and output voltage ripple.

Figure 1 shows the TPS63010EVM with the added soft start circuit (C5 and D1). Additionally, the output capacitance of the circuit is increased to draw more current during start up to better demonstrate the effectiveness of extending the soft start time. By feeding a current onto R2 through C5 and D1, the TPS63010's error amplifier reacts as if the output voltage is higher than it actually is and reduces the duty cycle accordingly. Thus, the output voltage increases slower. As the output voltage comes into regulation, C5 charges up and becomes more and more of an open circuit. Thus, soft start is ended and the error amplifier regulates the output voltage to the proper level.

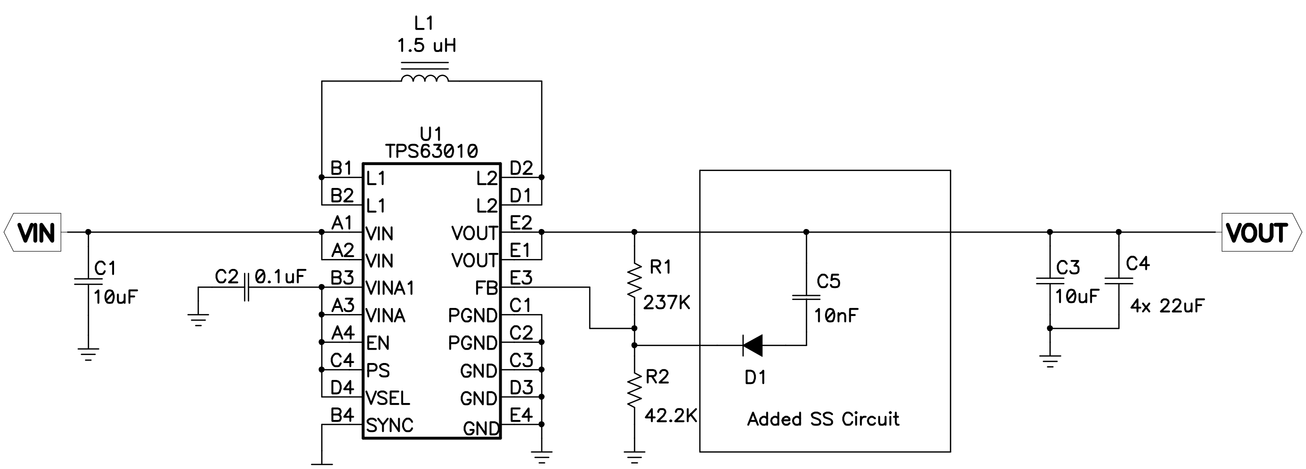

Figure 1. TPS63010EVM With Added Soft Start Circuit

Figure 2 shows the inrush current of the original TPS63010EVM with the increased output capacitance (98-µF total) starting into a 100-Ω load with a 3.6-V input voltage. Figure 3 shows the inrush current of the same circuit and load conditions but the soft start circuit has been added. The diode used in all tests was the small-signal, silicon diode DA2U101 from Panasonic.

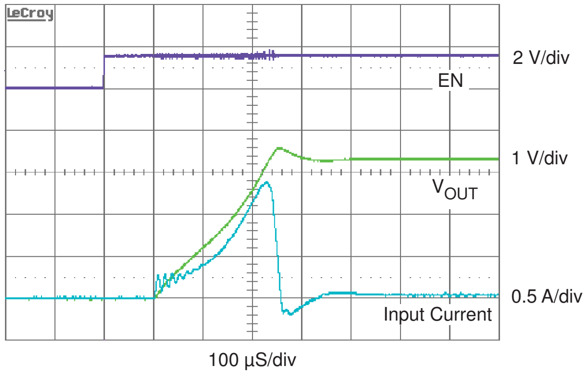

Figure 2. TPS63010EVM With Extra Output Capacitance Soft Starting Into 100-Ω Load – 250-µS Soft Start Time and 1.4 A of Inrush Current

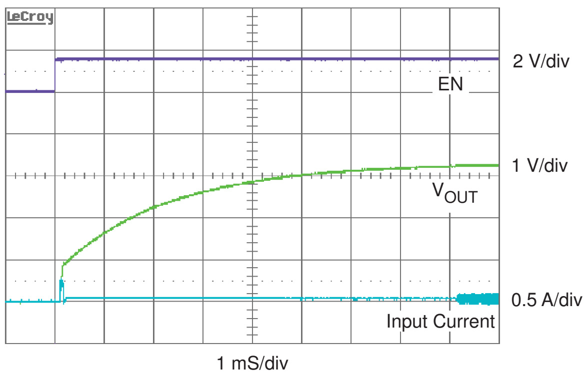

Figure 3. Figure 1 Circuit Soft Starting Into 100-Ω Load – 8-mS Soft Start Time and 300 mA of Inrush Current

3 Setting the Soft Start Time

The soft start time is roughly proportional to the product of R1 and C5. As this product goes up, the soft start time increases and the inrush current is reduced. If the product is too low, hardly any soft start time is added. Since the R1 value affects the current through the voltage divider, R1 and R2, adjusting C5 with a given R1 value is the preferred way of adjusting the soft start time. Note that the lowest achievable inrush current is around 400 mA, as this is what the TPS63010 supplies when it first turns on. This value is fixed inside the TPS63010 and cannot be reduced.

4 Alternative to the Basic Circuit

One limitation of the circuit in Figure 1 is that there is no discharge path for C5, besides the leakage currents of the capacitor itself and of the diode. Since the capacitor must be discharged to provide the extended soft start time, the lack of a clear discharge path means that it may not fully discharge if the circuit is disabled and then re-enabled relatively rapidly. Until leakage currents in D1 or C5 discharge C5, the next start up has a reduced soft start time. Comparing Figure 4 to Figure 3 shows the reduced start up time and higher inrush current that occurs with a relatively rapid re-enable after disable. Note that this is only an issue in systems that might have a rapid disabling and re-enabling of the TPS63010 or in systems that have a rapid re-application of input power after an input power loss. The effect on the soft start circuit is the same for either case–it is not discharged quickly enough to extend the soft start time on the next start up.

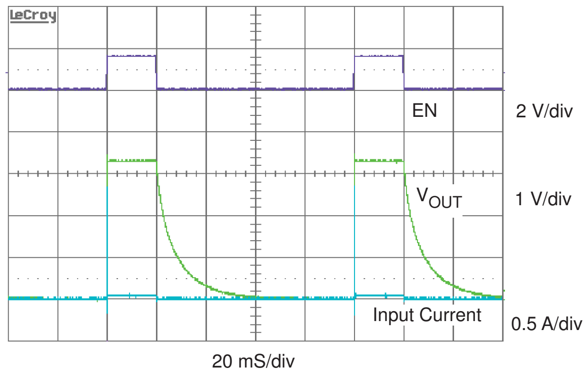

Figure 4. Figure 1 Circuit With EN Toggling at 10 Hz and 20% Duty Cycle – 1.4 A of Inrush Current

Figure 5 shows a solution to this possible issue. R3 provides a discharge path for C5, which resets the soft start circuit. Figure 6 shows the soft start circuit working properly on successive start ups, when R3 is added.

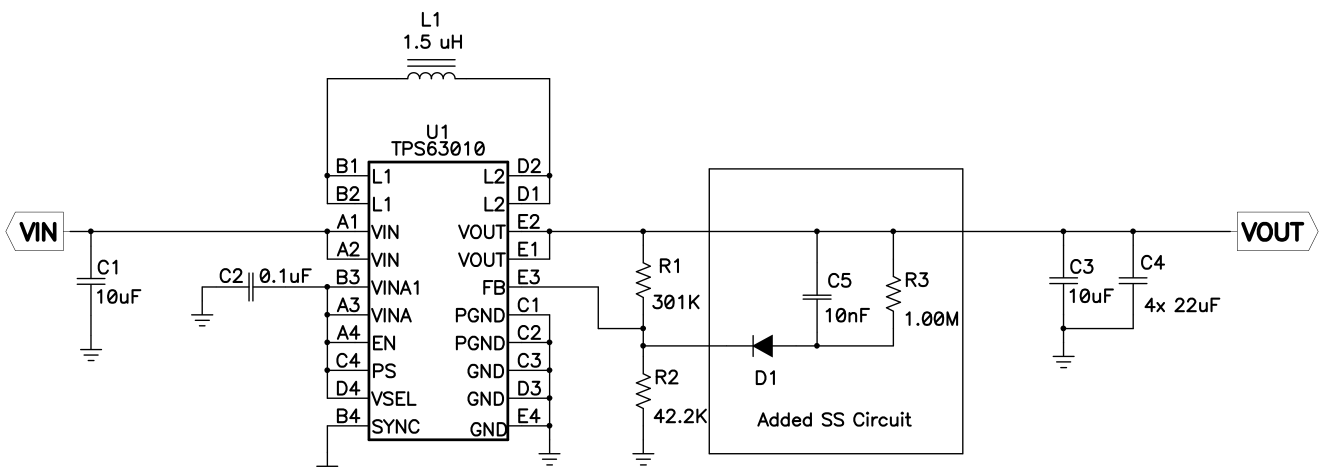

Figure 5. TPS63010EVM With Alternative Soft Start Circuit

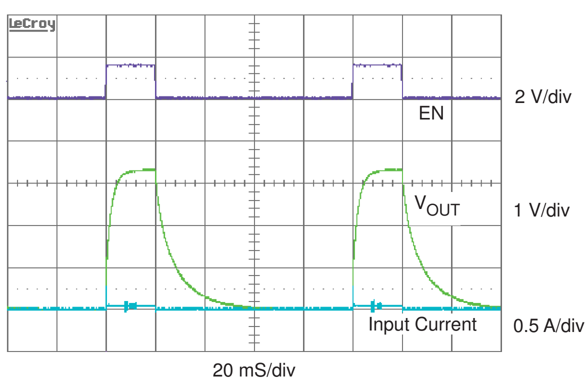

Figure 6. Figure 5 Circuit With EN Toggling at 10 Hz and 20% Duty Cycle – 300 mA of Inrush Current

As a side effect, R3 allows current to flow through D1 and onto the FB pin. Now the diode does not fully isolate the capacitor from the circuit, allowing some AC signals to be rectified through D1, while also offsetting the output voltage setpoint. Adjusting R1 resets the output voltage setpoint based on the current flowing from the output voltage, through R3 and D1, and onto the FB pin. Equation 1 gives the new formula for setting the output voltage:

$$\frac{V_{out} - V_{FB}}{R_1} + \frac{V_{out} - V_{FB} - V_D}{R_3} = \frac{V_{FB}}{R_2} \quad (1)$$

Where,

V_{out} (V): Desired output voltage

V_{FB} (V): FB pin voltage of 0.5 V

V_D (V): Forward voltage drop of D1

V_D should be measured on the diode or estimated from its datasheet. The diode used in these tests exhibits a forward voltage of around 0.3 V at the 2.5 µA of current that it carries. The larger the current in the feedback divider (R1 and R2) compared to the current through the diode and R3 resistor, the lower the impact of the diode's forward voltage on the overall output voltage setpoint. For example, the output voltage setpoint changes by only 1% when using 0.45 V as the forward voltage drop of the diode instead of 0.3 V. The effect of a changing forward voltage on the overall output voltage setpoint is calculated using Equation 1.

5 Transient Response

One way to see if the control loop is affected by these circuits is to look at the load step response and see if this response is changed significantly by the addition of the soft start circuitry. Figure 7 shows the resulting output voltage deviation of the TPS63010EVM with its increased output capacitance but no soft start circuit when subjected to a 100-mA to 1000-mA load step at a 3.6-V input voltage.

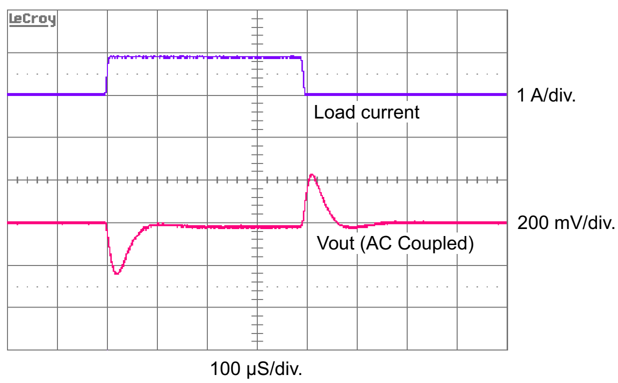

Figure 7. TPS63010EVM Load Transient Response With Extra Output Capacitance but Without Soft Start Circuit

Figure 8 shows the resulting output voltage deviation of the Figure 1 circuit when subjected to the same load step.

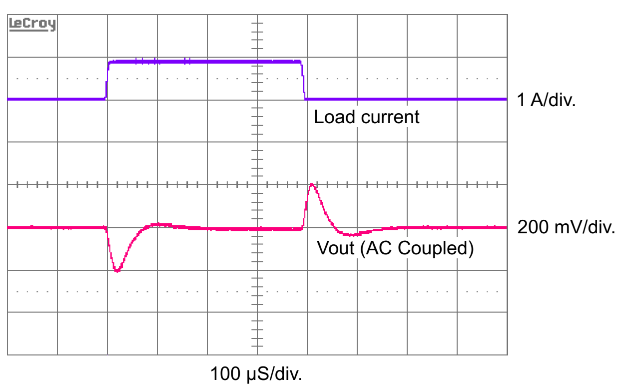

Figure 8. Figure 1 Circuit Load Transient Response

Figure 8 shows the resulting output voltage deviation of the Figure 5 circuit when subjected to the same load step.

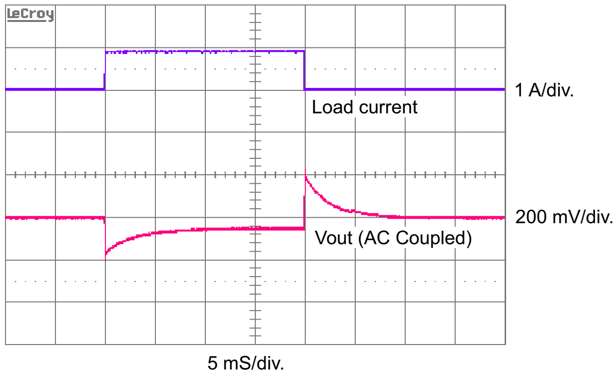

Figure 9. Figure 5 Circuit Load Transient Response

Because Figure 7 and Figure 8 are nearly identical, the Figure 1 soft start circuit has not affected the control loop significantly. Since Figure 8 shows a much slower response time, the Figure 5 soft start circuit has affected the control loop since the forward biased diode, D1, does not fully isolate C5 from the circuit. Though the soft start circuit achieves a faster discharge time when disabled, this circuit does have a slower transient response. However, the voltage deviations from the transient are the same compared to the TPS63010EVM with extra output capacitance circuit.

6 Load Regulation

Figure 10 compares the load regulation at a 3.6-V input voltage and 25 °C of Figure 1, Figure 5, and a TPS63010EVM circuit with extra output capacitance but without any added soft start circuit. Only the Figure 5 circuit shows some load regulation, which is acceptable for most applications. In addition, its R3 resistor causes the DA2U101's forward voltage drop, which varies over temperature, to impact the output voltage an additional 1% over temperature. This additional inaccuracy is calculated using the DA2U101's forward voltage drop from its datasheet (about 450 mV at cold and 150 mV at hot at 2.5-µA of forward current) in Equation 1. The effect of the diode's forward voltage drop is minimized with smaller R1 and R2 values. For example, when R1 is reduced to 10 kΩ and R2 to 59 kΩ, the same diode only has a 0.25% effect on the output voltage accuracy over temperature.

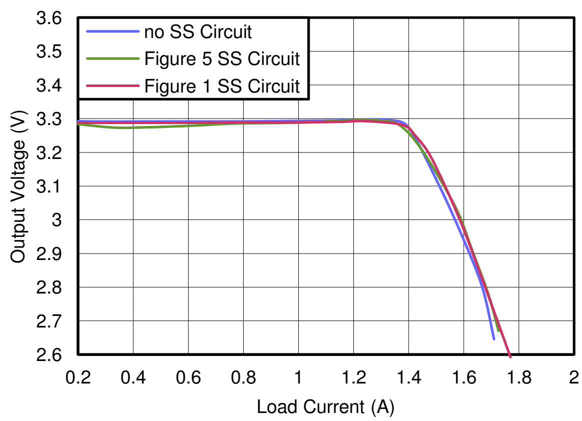

Figure 10. Load Regulation Effect of the Soft Start Circuits

7 Conclusion

This application report has demonstrated a simple circuit to extend the soft start time of the TPS63010 buck-boost converter, while also reducing the inrush current drawn from a battery. The addition of a capacitor and diode creates a user-programmable soft start time that obtains good load regulation, does not affect the control loop, and thus does not affect the circuit's response to a load step. A second circuit is also presented which, at the cost of slower transient response and poorer load regulation, allows an extended soft start time for systems in which the TPS63010 is disabled and re-enabled rapidly.

8 References

- *TPS63010 Datasheet* (SLVS653)
- *Design considerations for a resistive feedback divider in a DC/DC converter* (SLYT469)

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