Application Report

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Extending the Soft Start Time in the TPS6107x Family of Boost Converters

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Low Power DC-DC Applications

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 TPS6107x family of boost converters.

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1 TPS6107x Soft Start Operation

The TPS6107x has three cycles or phases of soft start:

- Cycle 1 (Precharge) charges the output capacitors to the input voltage. The internal synchronous FET operates in the linear region and delivers a DC, fixed current to the output capacitor during this phase, as shown in Figure 22 in the data sheet (SLVS510). The TPS6107x enters cycle 1 when enabled and Vin is above the undervoltage lockout. It exits cycle 1 after charging the output voltage up to a value that is almost equal to the input voltage.
- Cycle 2 (Fixed Duty Cycle Control) operates after cycle 1 ends. During cycle 2, the TPS6107x switches with a fixed 70% duty cycle. The TPS6107x enters cycle 2 when the cycle 1 is complete and the output voltage is less than 1.8 V. If the output voltage is greater than 1.8 V at the end of cycle 1, then cycle 2 is skipped. The TPS6107x only leaves cycle 2 when the output voltage is greater than 1.8 V.
- Cycle 3 (Reduced Current Limit) starts normal boost converter operation. During the third cycle of soft start, the error amplifier takes over and switches at the proper duty cycle, based on input and output voltage. During this cycle, the current limit is reduced to 50% of the nominal current limit to minimize inrush current. The TPS6107x enters cycle 3 directly from cycle 1 when the input voltage is greater than 1.8 V. It enters cycle 3 directly from cycle 2 when the input voltage is less than 1.8 V. The TPS6107x leaves cycle 3 and begins normal operation with the standard current limit when the output capacitor charges to the nominal output voltage.

2 Extending the Soft Start Time

The technique used in this application report to extend the soft start time adds an RC circuit 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. Figure 1 shows the TPS61070EVM with the added soft start circuit (C6, R3, and D1). By feeding a current onto R2 through C6 and D1, the TPS61070'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, C6 charges up and becomes more and more of an open circuit, while R3 pulls the remaining charge to ground. Thus, soft start is ended and the error amplifier regulates the output voltage to the proper level.

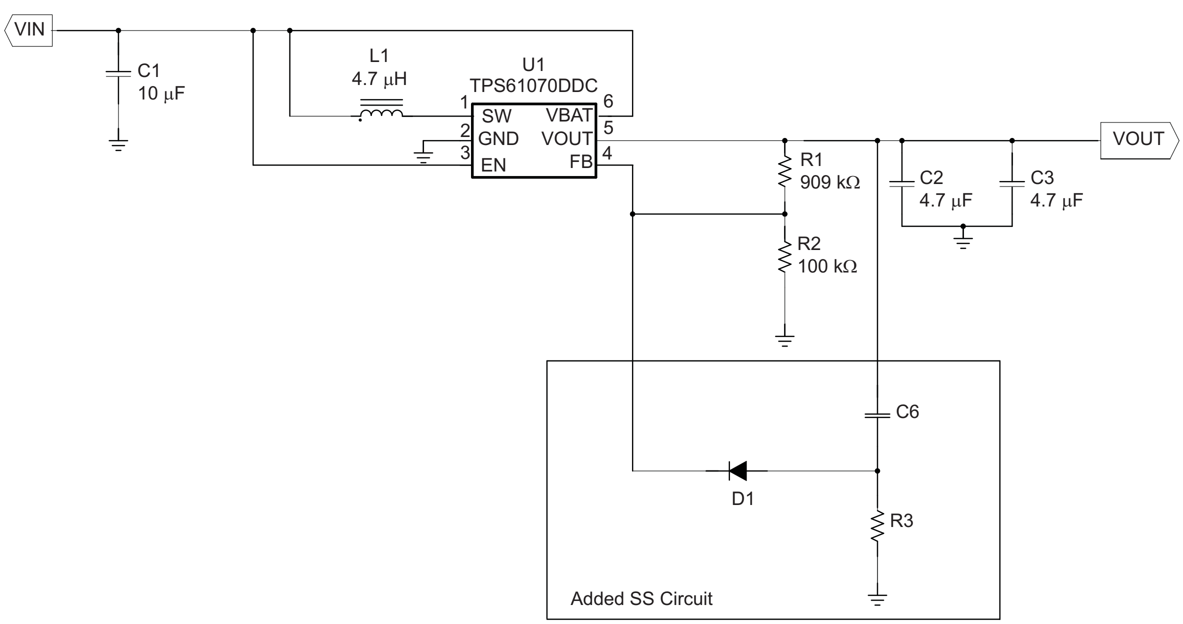

Figure 1. TPS61070EVM With Added Soft Start Circuit

Figure 2 shows the TPS61070EVM without any external soft start circuit starting into a 50-Ω load with 3.6-V input voltage. Figure 3 and Figure 4 show the same EVM and load conditions but the soft start circuit has been added. The diode used in these tests was the small signal, silicon diode 1N4148.

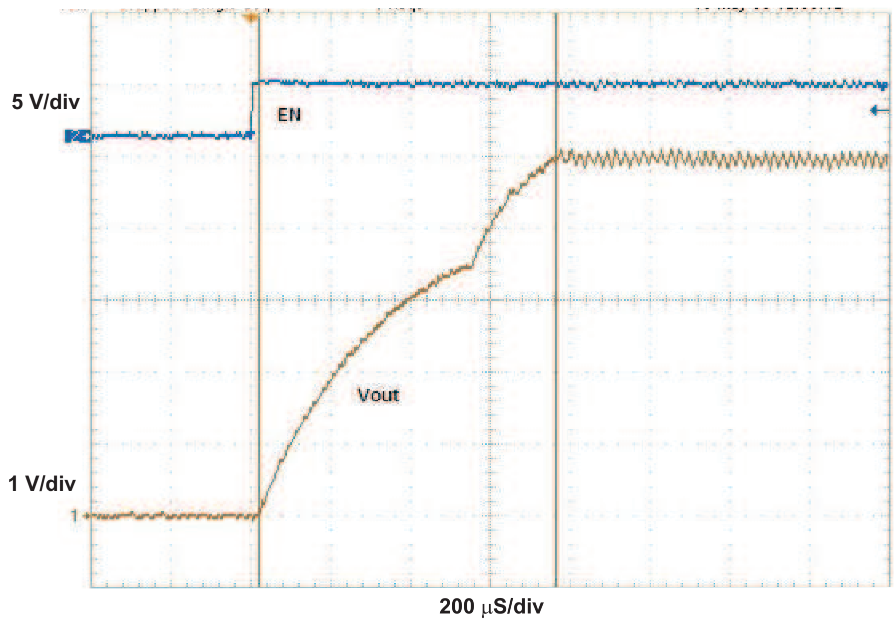

Figure 2. TPS61070EVM Soft Starting Into 50-Ω Load – 743-μs Soft Start Time

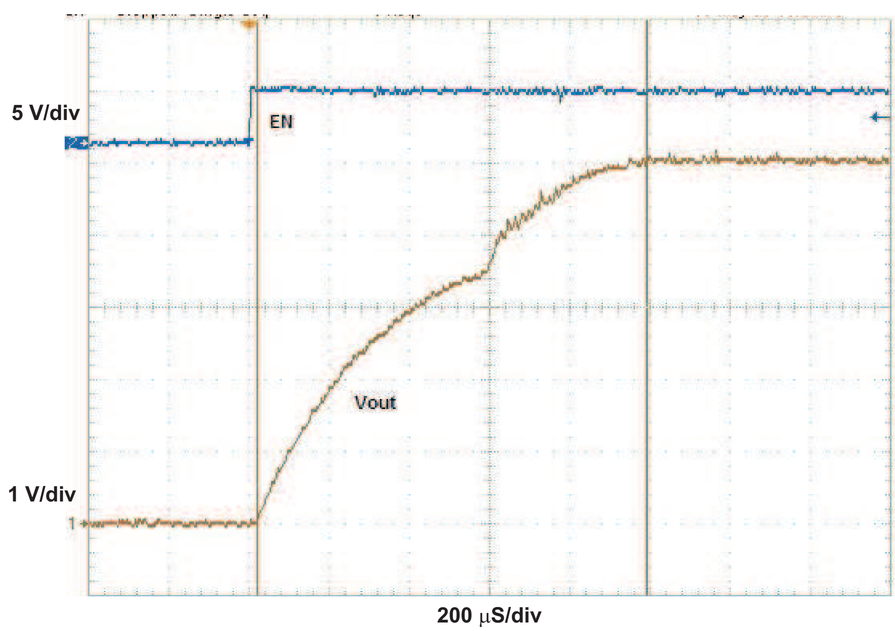

Figure 3. Figure 1 Circuit Soft Starting Into 50-Ω Load with C6 = 1000 pF and R3 = 162 kΩ – 971-μs Soft Start Time

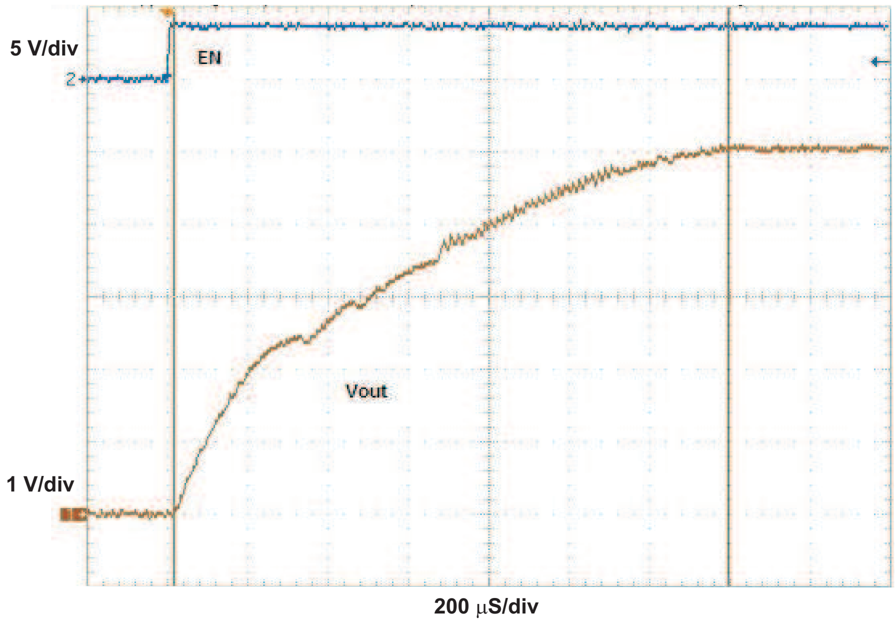

Figure 4. Figure 1 Circuit Soft Starting Into 50-Ω Load with C6 = 1800 pF and R3 = 162 kΩ – 1.379-ms Soft Start Time

3 Setting the Soft Start Time

The soft start time is roughly proportional to the product of R3 and C6. 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. Note that the allowable inrush current during the first cycle of soft start [Figure 22 in the TPS61070 data sheet (SLVS510)] cannot be reduced.

Table 1 shows measured soft start times with various values of R3 and C6. The amount of output capacitance and expected load during start-up are also critical factors in determining the soft start time for a particular application. Table 1 should be used as a guide to selecting R3 and C6. Laboratory verification is necessary to ensure a particular soft start time for a given system with a given output capacitance and load in the midst of component variation over tolerance and temperature.

Table 1. Soft Start Times and Inrush Currents of the Figure 1 Circuit With Different Values of C6 and R3

R3 (Ω)	C6 (nF)	Soft Start Time (1) (ms)	Peak Inrush Current (2) (mA)
10 k	1.8	0.8	200
10 k	15	1.1	120
10 k	47	3.2	100
10 k	100	6.4	100
10 k	150	9.5	100
162 k	1	1.0	120
162 k	1.8	1.4	100
162 k	4.7	3.8	100
162 k	10	7.8	100
162 k	15	11.2	100

(1) Measured on the Figure 1 Circuit with 3.6 V input and 50-Ω load

(2) Measured on the Figure 1 Circuit with two depleted AA batteries (~2.1 V) and 500-Ω load

4 Transient Response

One way to see if the control loop is affected is to look at the response of the circuit to a load step and see if this response is changed significantly by the addition of the soft start circuitry.

Figure 5 and Figure 6 show the resulting output voltage deviation of the Figure 1 circuit when subjected to a 20-mA to 180-mA load step. (Note: during light load (20 mA), the TPS61070 goes into PFM mode, so the output ripple is larger).

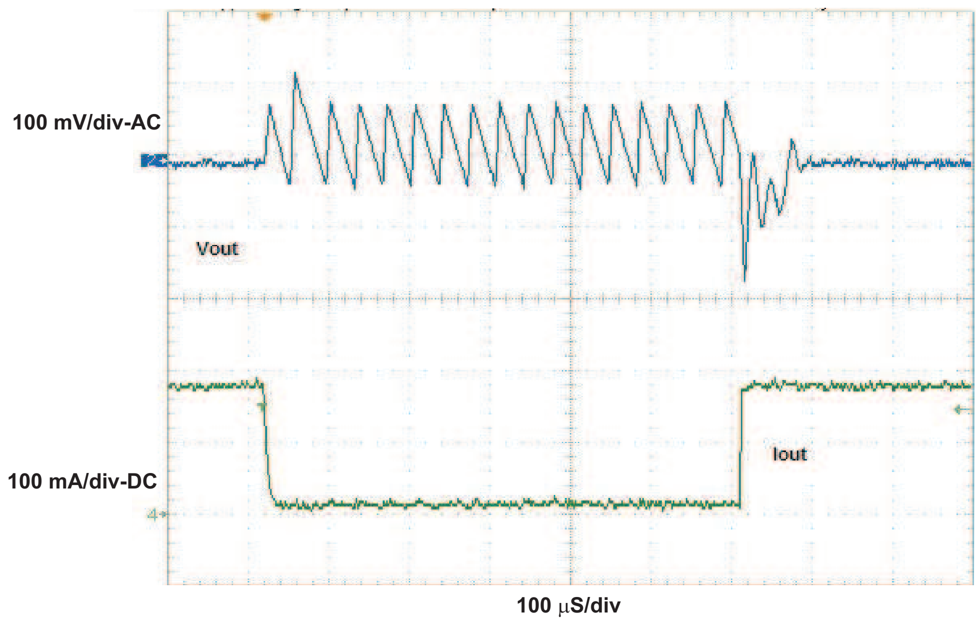

Figure 5. TPS61070EVM Transient Response Without Soft Start Circuit

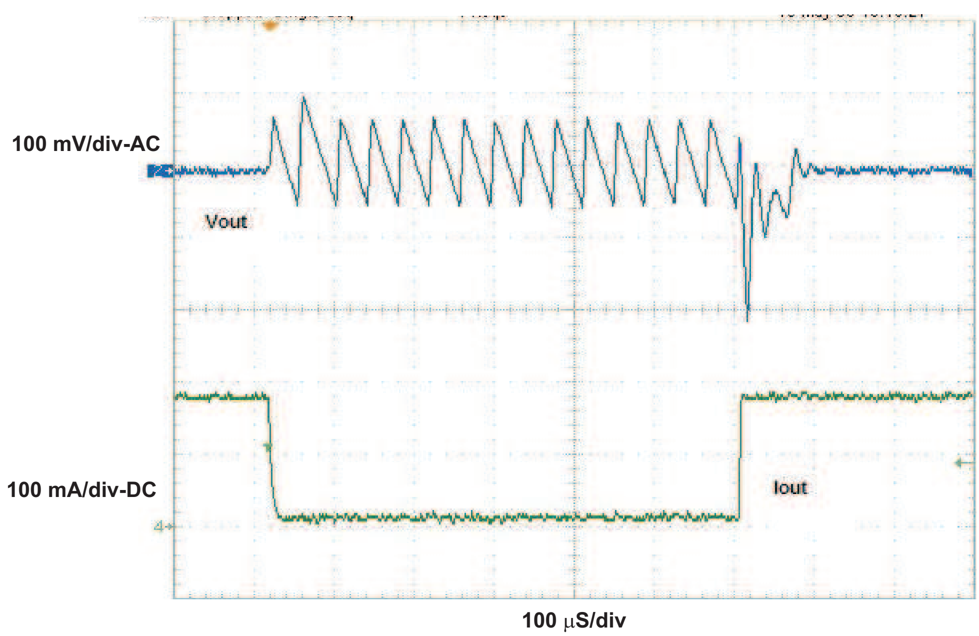

Figure 6. Figure 1 Circuit Transient Response With C6 = 1800 pF and R3 = 162 kΩ

Because Figure 5 and Figure 6 are nearly identical, the added soft start circuit has not affected the control loop significantly.

5 Inrush Current Reduction

Figure 7 and Figure 8 demonstrate how the additional soft start circuitry reduces the sagging battery voltage caused by the large inrush current at turn on. Two AA batteries connected in series with a combined voltage of 2.1 V power the TPS61070EVM, which has a 500-Ω load. Without the soft start circuitry, the TPS61070 has an inrush current of 200 mA, which results in a battery voltage droop of 260 mV. With the soft start circuit, the inrush current is only 100 mA, which results in a 140-mV droop in battery voltage.

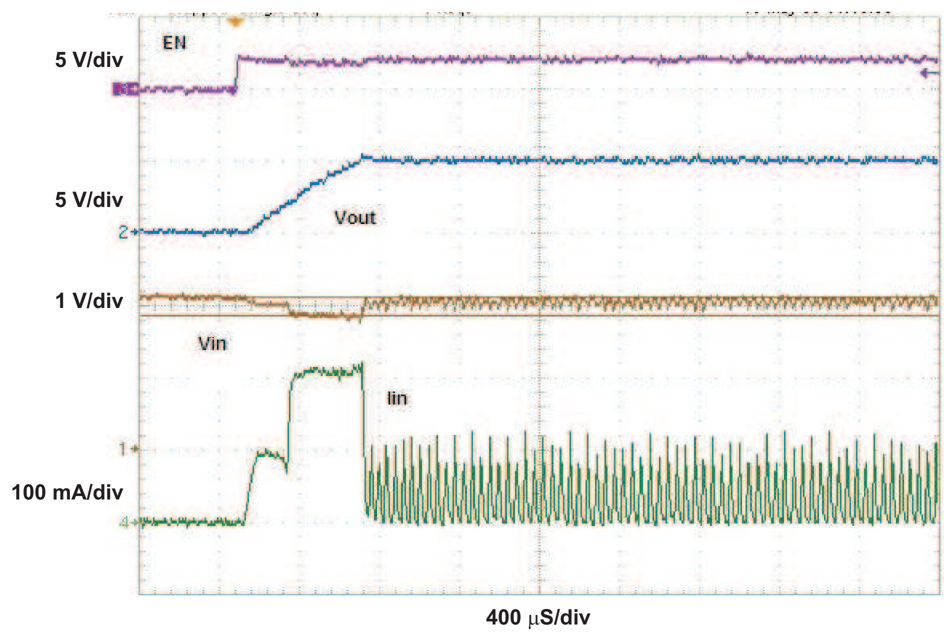

Figure 7. TPS61070EVM Start-up Powered From Two AA Batteries Without Soft Start Circuit

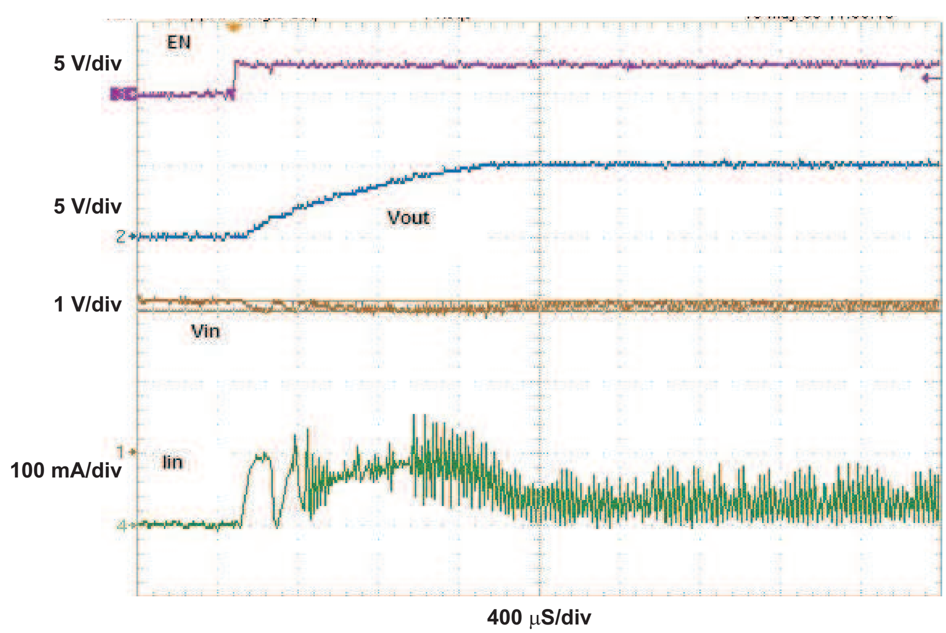

Figure 8. Figure 1 Circuit Start-up Powered From Two AA Batteries With C6 = 1800 pF and R3 = 162 kΩ

6 Load Regulation

The added soft start circuit has the possibility of introducing some additional output voltage regulation (load regulation) depending on the operating conditions of the circuit and the specific device and component values used. Figure 9 shows that the added soft start circuit with C6 = 15 nF and R3 = 162 kΩ does not worsen the load regulation more than the TPS61070EVM without the soft start circuit. Therefore, the soft start circuit does not create any additional load regulation on the TPS61070. If this circuit is used with other devices, the load regulation should be checked.

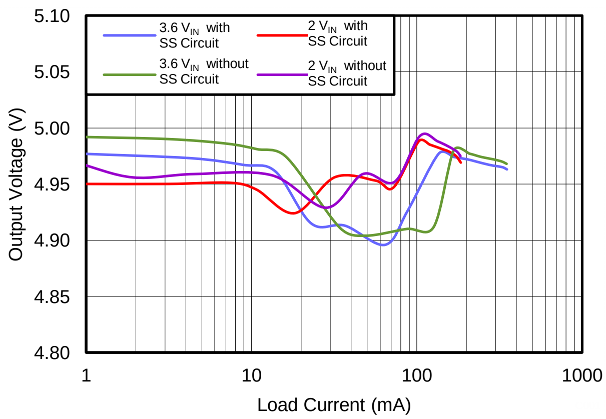

Figure 9. Load Regulation Effect of the Soft Start Circuit

7 Conclusion

This application report has demonstrated a simple circuit to extend the soft start time of the TPS6107x family of boost converters, while also reducing the inrush current drawn from a battery. The addition of a resistor, capacitor, and diode creates a user-programmable soft start time that does not affect the control loop and thus does not affect the circuit's response to a load step or its load regulation. This basic circuit is applicable in principal to any TPS6xxxx device. Checking the load regulation and control loop stability should be done to assess its applicability to specific devices besides the TPS6107x family.

8 References

- *TPS61070 Datasheet* (SLVS510)
- *Design considerations for a resistive feedback divider in a DC/DC converter* (SLYT469)

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