

Extending the Soft Start Time Without a Soft Start Pin

Chris Glaser

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.

Contents

1	TPS6107x Soft Start Operation	2
2	Extending the Soft Start Time	2
3	Setting the Soft Start Time	4
4	Transient Response	5
5	Inrush Current Reduction	6
6	Load Regulation.....	7
7	Conclusion	7
8	References	7

List of Figures

1	TPS61070EVM With Added Soft Start Circuit	2
2	TPS61070EVM Soft Starting Into 50-Ω Load – 743-μs Soft Start Time.....	3
3	Figure 1 Circuit Soft Starting Into 50-Ω Load with C6 = 1000 pF and R3 = 162 kΩ – 971-μs Soft Start Time .	3
4	Figure 1 Circuit Soft Starting Into 50-Ω Load with C6 = 1800 pF and R3 = 162 kΩ – 1.379-ms Soft Start Time	4
5	TPS61070EVM Transient Response Without Soft Start Circuit	5
6	Figure 1 Circuit Transient Response With C6 = 1800 pF and R3 = 162 kΩ.....	5
7	TPS61070EVM Start-up Powered From Two AA Batteries Without Soft Start Circuit	6
8	Figure 1 Circuit Start-up Powered From Two AA Batteries With C6 = 1800 pF and R3 = 162 kΩ	6
9	Load Regulation Effect of the Soft Start Circuit.....	7

List of Tables

1	Soft Start Times and Inrush Currents of the Circuit With Different Values of C6 and R3.....	4
---	---------------------------------------------------------------------------------------------	---

Trademarks

All trademarks are the property of their respective owners.

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 V_{in} 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.

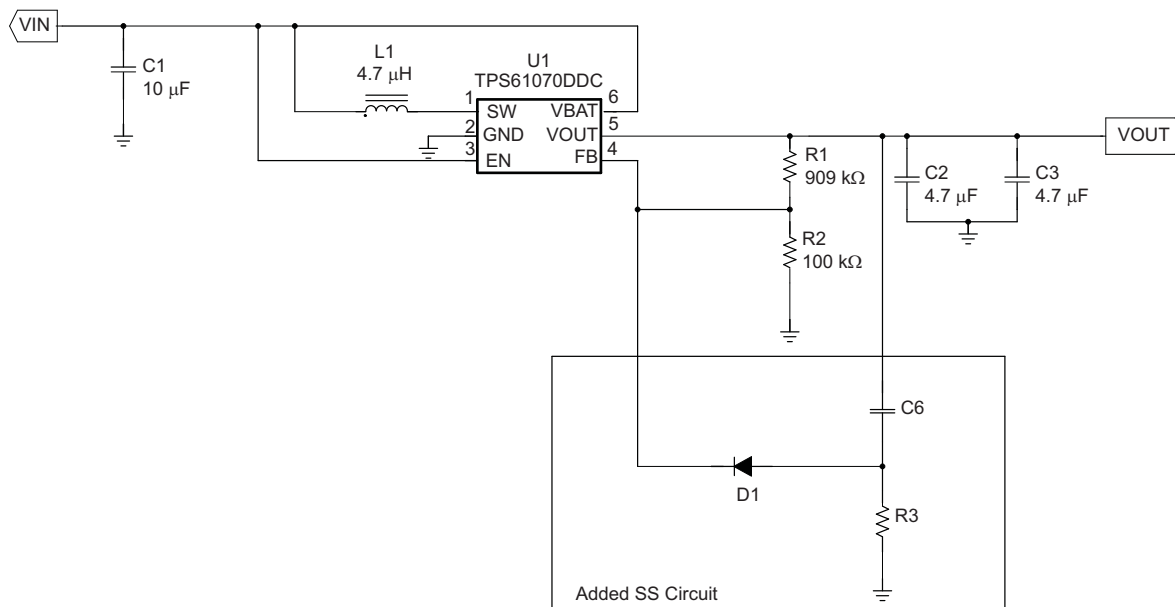


Figure 1. TPS61070EVM With Added Soft Start Circuit

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.

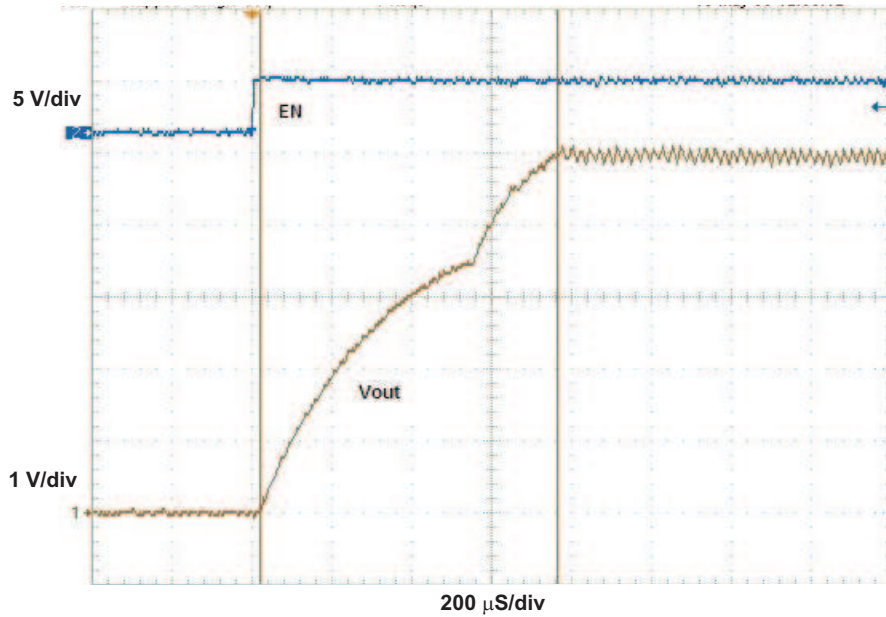


Figure 2. TPS61070EVM Soft Starting Into 50-Ω Load – 743-μs Soft Start Time

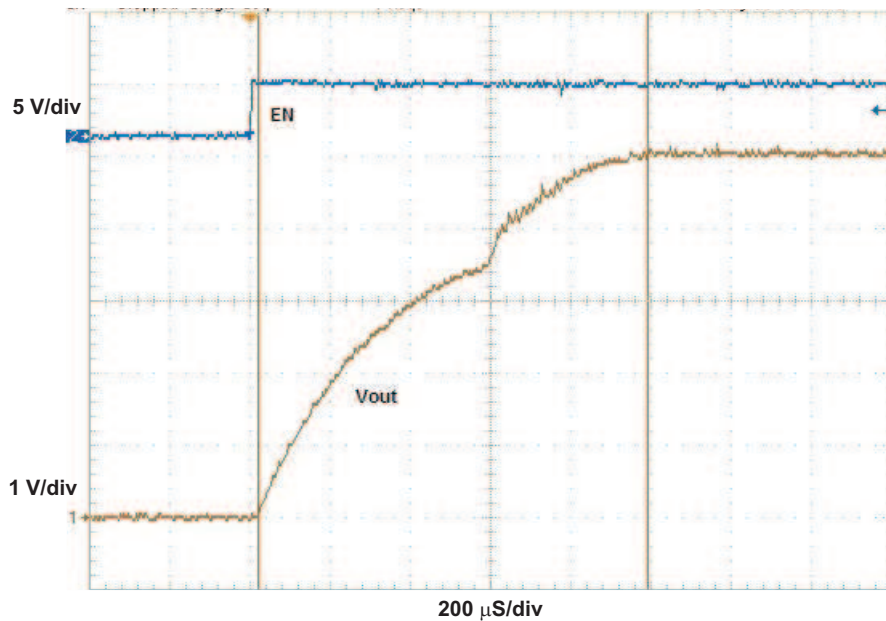


Figure 3. Figure 1 Circuit Soft Starting Into 50-Ω Load with C6 = 1000 pF and R3 = 162 kΩ – 971-μs Soft Start Time

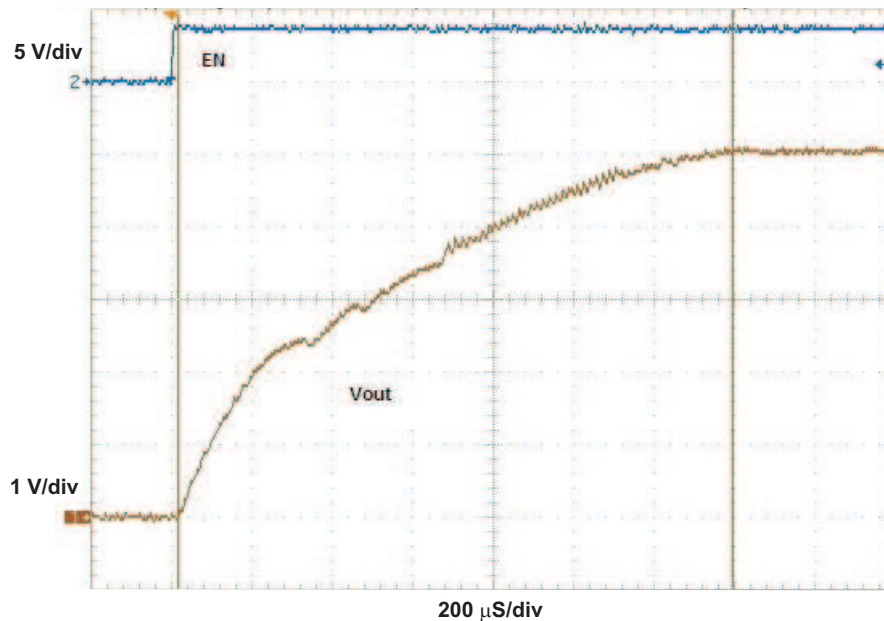


Figure 4. Figure 1 Circuit Soft Starting Into 50-Ω Load with C6 = 1800 pF and R3 = 162 kΩ – 1.379-ms Soft Start Time

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).

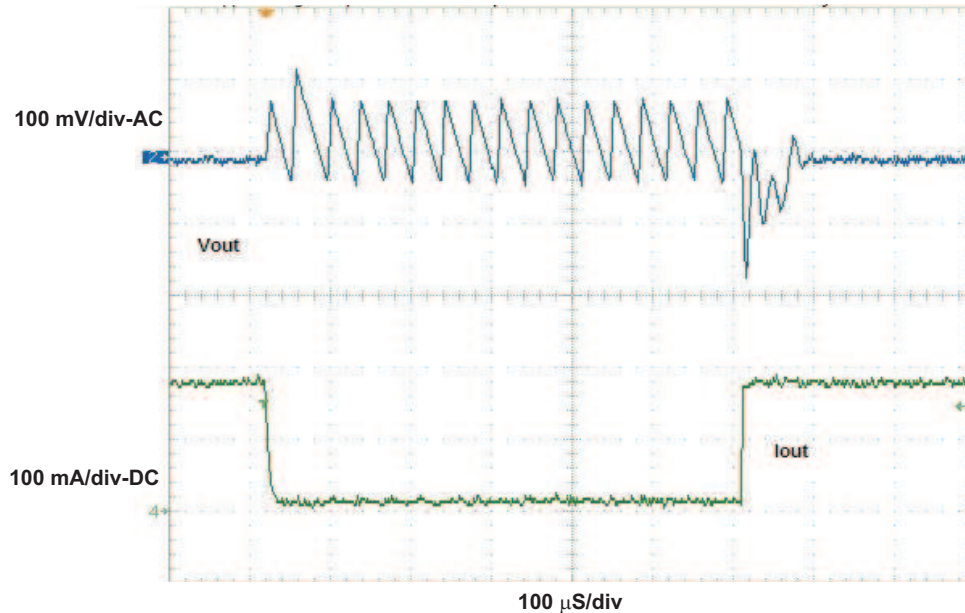


Figure 5. TPS61070EVM Transient Response Without Soft Start Circuit

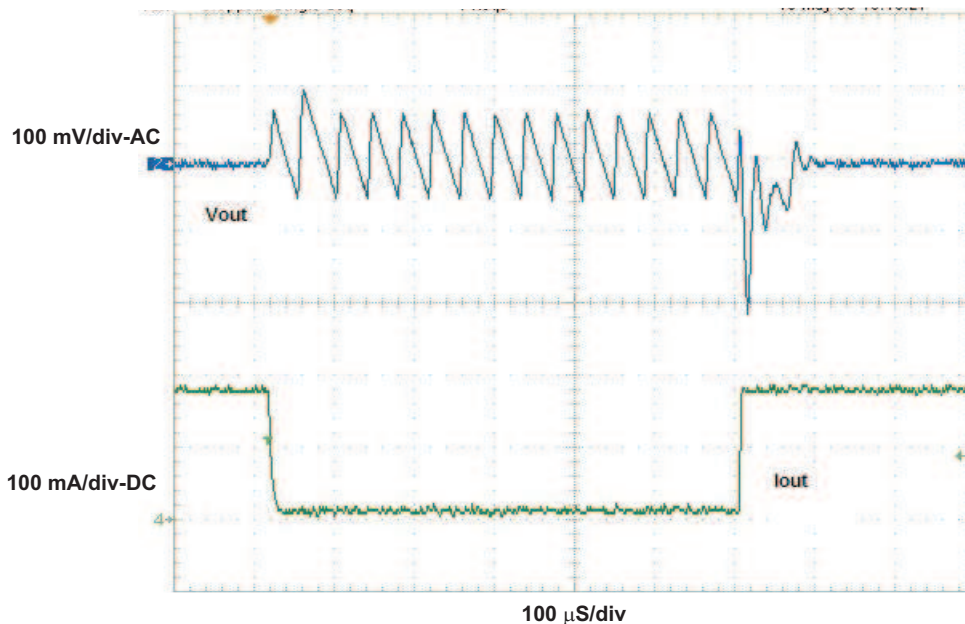


Figure 6. Figure 1 Circuit Transient Response With C6 = 1800 pF and R3 = 162 kΩ

Because Figure 5 and Figure 6 are nearly identical, the added soft start circuitry 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.

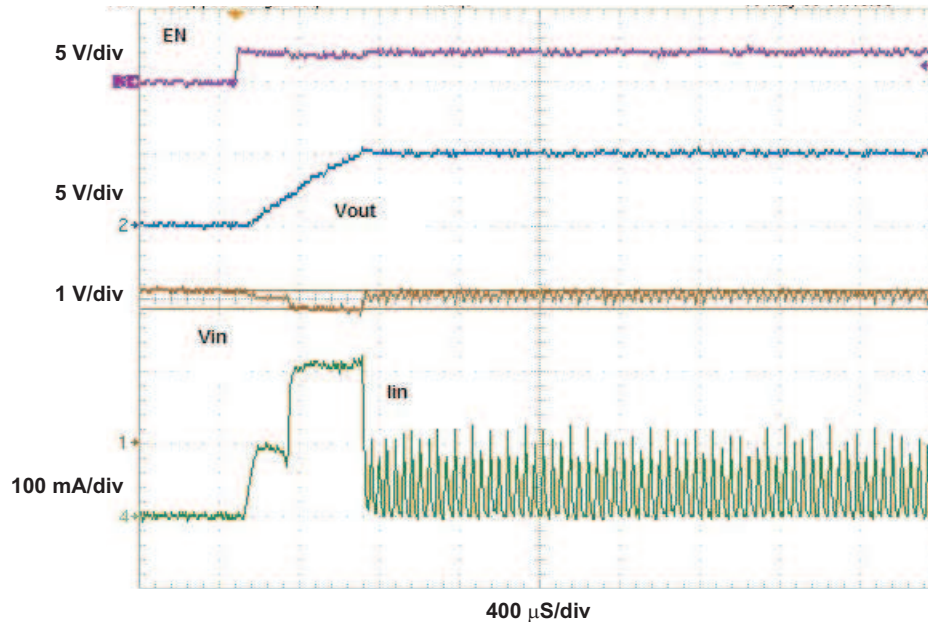


Figure 7. TPS61070EVM Start-up Powered From Two AA Batteries Without Soft Start Circuit

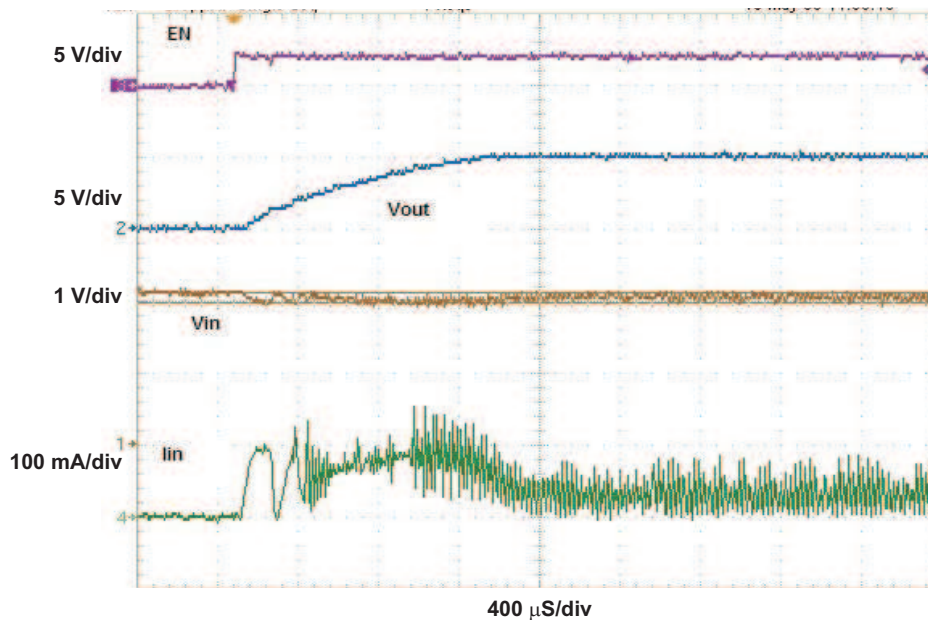


Figure 8. Figure 1 Circuit Start-up Powered From Two AA Batteries With C6 = 1800 pF and R3 = 162 kΩ

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 $C6 = 15 \text{ nF}$ and $R3 = 162 \text{ k}\Omega$ 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.

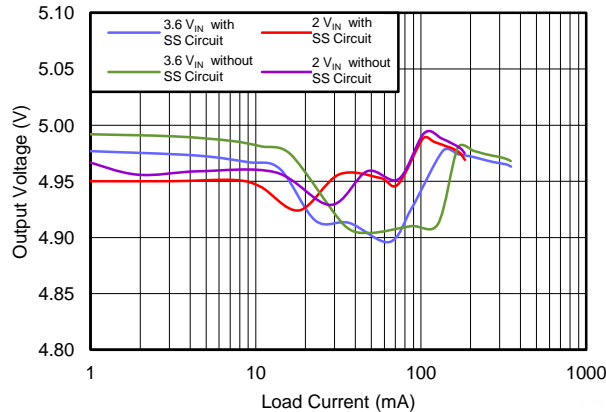


Figure 9. Load Regulation Effect of the Soft Start Circuit

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 \(SLYT469\)](#)

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from A Revision (February 2013) to B Revision

Page

- | Changes from A Revision (February 2013) to B Revision | Page |
|-------------------------------------------------------|------|
| • Changed document title. | 1 |

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ("TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI's standard terms for semiconductor products (<http://www.ti.com/sc/docs/stdterms.htm>), [evaluation modules](#), and [samples](http://www.ti.com/sc/docs/sampterm.htm) (<http://www.ti.com/sc/docs/sampterm.htm>).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2017, Texas Instruments Incorporated