ABSTRACT

This application report outlines a robust solution to prevent the lockup of the TPS65217 device in the event of a brownout condition on the input voltage ($V_{IN}$). Designs using the TPS65217 device can experience the lockup when the input voltage drops unexpectedly and returns to stable operation without dropping fully to the ground potential (0 V), which is commonly referred to as a brownout fault. A solution is provided to avoid a lockup condition for systems both with and without a battery.

Contents

1 Introduction .............................................................. 2
2 Application Overview .................................................. 4
3 Solution Description ..................................................... 8
4 Summary .................................................................. 12
5 References ................................................................. 12

List of Figures

1 TPS65217 Global State Diagram ........................................... 3
2 TPS65217 Typical Application Circuit ...................................... 4
3 TPS65217 Application Case A ............................................. 5
4 TPS65217 Application Case B ............................................. 6
5 TPS65217 Application Case C ............................................. 7
6 Solution Circuit Number 1 .................................................. 8
7 Solution Circuit Number 2 .................................................. 9
8 TPS65217 Lockup Condition Without a Battery Because of Capacitance on VBAT ....................... 9
9 TPS65217 VIN Brownout Recovery With Solution Circuit Number 2 .................................. 10
10 Solution Circuit Number 3 ............................................... 10
11 TPS65217 Lockup Condition With a Battery Because of PPATH Changeover .......................... 11
12 TPS65217 VIN Brownout Recovery With Solution Circuit Number 3 .................................. 11

List of Tables

Trademarks

Sitara is a trademark of Texas Instruments.
ARM, Cortex are registered trademarks of ARM Ltd.
All other trademarks are the property of their respective owners.
1 Introduction

The TPS65217 device is a power management integrated circuit (PMIC) that pairs ideally with AM335x ARM® Cortex®-A8 microprocessors and is widely used in portable consumer electronics because it is used in the popular BeagleBone Black reference design. Neither the BeagleBone Black nor the TPS65217CEVM ship with a Li-ion battery included as part of the kit, but a battery is included in the typical application circuit of the TPS65217 in the datasheet[1].

When a designer first begins developing a new product based on either the BeagleBone Black or one of the TPS65217 EVMs, understanding the intended application of the TPS65217 device is critical to successfully design products using this PMIC.

The TPS65217 device was originally intended for applications with a removable or closely-monitored single-cell Li-ion battery pack, a physical push-button, and a plug/unplug-capable AC-DC 5-V charger (for example, a barrel-jack adapter or mini-B USB port) that reliably connects to power the PMIC. The following applications of the TPS65217 can push the device beyond its normal operating conditions:

- **Nonideal**: Systems that do not require a battery (no connection to BAT or BAT_SENSE pins)
  - **Suggested usage**: The TPS65217 device is used in a system with a single-cell Li-Ion battery with a physical push-button connected to the PB_IN pin
- **Nonideal**: A separate DC-DC converter provides a reference for the I/O voltage pins of the TPS65217 device (connected to the VIO pin) and is not disabled when a fault occurs on the input voltage rails
  - **Suggested usage**: The TPS65217 device is the central power supply in the system which is enabled first then disabled last, and a fault condition also disables other DC-DC converters in the system
- **Nonideal**: The system relies entirely on the TPS65217 device to handle battery charging and the voltage is not closely monitored by the processor
  - **Suggested usage**: The BAT voltage is routed through the MUX_OUT pin to an ADC of the processor and is only permitted to enter a UVLO condition by a natural occurrence of battery self-discharge

Implementing any one of the nonideal applications of the TPS65217 device puts the system at risk of experiencing a lockup as a result of a brownout condition on the input voltage. The solution circuits provided in this application report are for preventing a lockup when the suggested usage cannot be implemented to avoid nonideal applications.

The TPS65217 device has two optional connections for input power, named AC and USB, and, for simplicity, the term $V_{IN}$ is used in this document to refer to either the AC or USB input. A brownout of $V_{IN}$ should always be avoided, but additional precautions must be taken when one of the aforementioned nonideal applications is implemented.

---

**NOTE:** Pressing the push-button is mandatory for powering-on the TPS65217 device when only battery power is available and, as a result, all applications of the TPS65217 device that use a battery must also include a physical push-button. The push-button is shown on all circuits or block diagrams in this application report when a battery is used in the system, but the presence of a push-button is not directly related to the lockup resulting from a brownout condition on $V_{IN}$.

The battery is the primary power supply for the TPS65217 device. When $V_{IN}$ experiences a brownout condition and the BAT voltage is below UVLO, the TPS65217 device identifies this as a fault. The device opens the AC (or USB) switch and closes the switch between SYS and BAT even if a battery is not present. If $V_{IN}$ recovers and returns to a normal operating voltage (typically 5 V) before the 1-s fault timer expires or the POWER DOWN state is entered naturally (no voltage at any input power pin), a lockup can occur.

**Figure 1** shows the state diagram of the TPS65217 device which should be referenced frequently while discussing the brownout and lockup issues.
The following sections of this application report outline some of these unintended applications of the TPS65217 device. For each unintended application, a simple yet robust solution is proposed with the intended purpose of avoiding lockup as a result of a brownout condition on $V_{\text{IN}}$.
Application Overview

2 Application Overview

Figure 2 shows the typical (ideal) application of the TPS65217 device.

Figure 2. TPS65217 Typical Application Circuit
2.1 Case A: Nonideal TPS65217 Application Without a Battery

The first nonideal application of the TPS65217 that is discussed is labeled Case A and is defined by the absence of a battery. Figure 3 shows an example of this type of application. For simplicity, Figure 3 only shows the input power pins and other required connections for the TPS65217 device.

![Figure 3. TPS65217 Application Case A](image)

Because neither the BeagleBone Black nor the TPS65217 EVMs ship with a Li-ion battery included as part of the kit, a final product using the TPS65217 and an AM335x processor is assumed to not require a battery. Although designing for the TPS65217 and AM335x devices without a battery is possible, the TPS650250, TPS65910, and TPS65218 PMICs offered by TI are better suited for AM335x applications without a battery because they do not integrate a charger for the main Li-ion battery. The TPS65910 and TPS65218 PMICs are also supported by drivers included in the TI Linux kernel for AM335x Sitara™ processors.

Assuming the TPS65217 device must be used because the system requires the WLED boost or the design schedule is tight and known-working reference designs must be copied, the TPS65217 device can be used in a system without a battery. For Case A systems without a battery, continue reading Section 3 to decide between implementing solution circuit number 1 or solution circuit number 2 to avoid causing a lockup.
2.2 Case B: Nonideal TPS65217 Application Without a Battery, With External Voltage Applied to VIO

The second nonideal application of the TPS65217 that is discussed is labeled Case B and is defined as a system without a battery where an external voltage is applied to the VIO pin of the TPS65217 device. The external voltage applied to VIO is typically 3.3 V from a discrete DC-DC buck regulator that allows GPIOs on the processor to operate before the PWR_EN input of the TPS65217 device is driven high. Figure 4 shows an example of this type of application.

In this application, when a voltage is applied at the VIO pin and a brownout occurs on $V_{IN}$, the BAT and SYS pins will have a voltage present because of a leakage path in the device. The IO pins generally cannot be driven high when no input power is applied to a device, and this is exactly what is occurring in Case B. The result is that Case B is effectively the same as Case C (Section 2.3) and should be treated as a system with a battery. Therefore, lockups that are identified in either Case B and Case C applications are both resolved by implementing solution circuit number 3 (Section 3.3).
2.3 Case C: Nonideal TPS65217 Application With a Battery

The final nonideal application of the TPS65217 that is discussed is labeled Case C and is defined by the inclusion of a battery where the voltage of the battery has dropped below UVLO when a brownout on $V_{IN}$ occurs. Figure 5 shows an example of this type of application.

![Diagram of TPS65217 Application Case C](https://www.ti.com/lit/ds/slaavj03a/slaavj03a.pdf)

**Figure 5. TPS65217 Application Case C**

If a brownout occurs on the $V_{IN}$ voltage for <1 s when the voltage on the battery (VBAT pin) is below the undervoltage lockout (UVLO) set point, a lockup can still occur even though Case C closely resembles the ideal application circuit. Fortunately, this lockup can also be avoided with a robust solution that requires only a few external components connected to the TPS65217 device.
3 Solution Description

The solution required to workaround the lockup caused by a brownout on $V_{IN}$ depends on the application of the TPS65217 device in the system. Case A applications without a battery can be resolved with solution circuit number 1 or 2, depending on whether $V_{IN}$ will remain below 5.5 V in the system. Case B and Case C applications can both be solved by implementing solution circuit number 3.

NOTE: When implementing any of the three hardware solution circuits, TI recommends adjusting the UVLO of the TPS65217 device to the value required by the chemistry of the battery used. When a battery is not present, the lowest UVLO voltage reduces the chances of a brownout condition occurring. For example, the UVLO voltage can be changed to the lowest setting (2.73 V) by instructing the firmware of the processor to change register 0x18 to a value of 0x00 (set the UVLO[1:0] bit to 00b) during its initialization routine.

3.1 Solution Circuit Number 1 for Case A (No Battery)

When no battery is used in the system, the simplest way to prevent a lockup is to connect the power supply to the primary power path of the TPS65217 device at the BAT pins. Solution circuit number 1, shown in Figure 6, is also proposed in the TPS65217 datasheet when $V_{IN_{max}} \leq 5.5$ V and the overvoltage protection of the AC (or USB) inputs is not required. A push-button must now be used to power-on the system because the input voltage is not discernible from an actual battery.

![Figure 6. Solution Circuit Number 1](image-url)
### 3.2 Solution Circuit Number 2 for Case A (No Battery)

When no battery is used in the system and \( V_{\text{IN max}} \geq 5.5 \, \text{V} \), \( V_{\text{IN}} \) must be applied at the AC (or USB) input of the TPS65217 device. Figure 7 shows the second workaround to prevent a lockup. This workaround requires only one passive component, a light-load resistor (\( R_{\text{LL}} \)) connected from the BAT pin to GND, to replace the capacitor normally recommended in the design.

![Solution Circuit Number 2](image)

**Figure 7. Solution Circuit Number 2**

Connecting a large bypass capacitor (>10 \( \mu \text{F} \)) to the BAT pin essentially provides a very small battery for the system. This capacitor is not be detected as a battery by the BAT\_SENSE pin, but it holds a charge when voltage is applied. The resulting waveform will look similar to Figure 8.

![Waveform](image)

**Figure 8. TPS65217 Lockup Condition Without a Battery Because of Capacitance on VBAT**

To resolve this issue, a light-load resistor (\( R_{\text{LL}} = 1 \, \text{k}\Omega \) to 10 \( \text{k}\Omega \)) can be used to replace the capacitor so the BAT pin will not hold any charge. The waveform using this solution will look like Figure 9 and the system will recover from the brownout on \( V_{\text{IN}} \) without any lockup behavior.
3.3 Solution Circuit Number 3 for Case B and Case C

Figure 10 shows the lockup condition in Cases B and C depicted as a timing diagram.

NOTE: Although using TI components for the workaround is not required, TI recommends using equivalent devices. The supervisor with delay must have equivalent or better performance compared to the LP3470 device. The load switch must have equivalent or better performance compared to the TPS22958 device.
Solution circuit number 3 is necessary because the voltage on the battery ($V_{\text{BAT}}$) does not continue to discharge during the brownout condition on $V_{\text{IN}}$ (directly connected to AC). When $V_{\text{IN}}$ drops below the $\text{UVLO}_{\text{PMIC}}$ threshold the DC-DC converters and LDOs (or load switches), are shut down, but the SYS pin is still connected to the BAT pin through the power path (PPATH). Both the BAT and SYS pins maintain a steady voltage. The 1-s fault does not expire and the recovery of the AC voltage after the brown-out is not detected.

Avoiding a lockup can only be achieved by preventing the brownout on $V_{\text{IN}}$ upstream from the TPS65217 device. Solution circuit number 3 implements an external supervisor with a delay timer controlling a load switch when $\text{UVLO}_{\text{EXT}} > \text{UVLO}_{\text{PMIC}}$ and $t_{\text{delay}} \geq 2$ s.

When solution circuit number 3 is implemented, the resulting waveform is as shown in Figure 12. The circuitry upstream from AC causes a deliberate cutoff of $V_{\text{IN}}$ when the supervisor circuit senses a $\text{UVLO}_{\text{EXT}}$ condition. The supervisor disables the load switch from the AC pin and the supervisor does not re-enable the load switch until $V_{\text{IN}}$ recovers and a delay timer of >2 s expires.

With the solution circuit added, the 1-s fault timer of the TPS65217 device expires before the 2-s delay timer of the external supervisor. The AC voltage is correctly detected when $V_{\text{IN}}$ is reapplied through the load switch.
4 Summary

In summary, the TPS65217 device is an excellent PMIC to be paired with the AM335x processors in a variety of applications. This application report can help assist designers to avoid a lockup condition resulting from a brownout fault on $V_{IN}$ and deviations from the intended application of the TPS65217 device.

When the TPS65217 device is used in an application without a battery, the simplest solution may be selecting another PMIC that is better suited for the application. If the TPS65217 device is still best for the application, the lockup can be prevented by simply modifying passive component selection.

In applications where the TPS65217 device is used with a battery but the battery voltage is low when a brownout occurs (or a battery with low voltage appears to be present due to a separate power supply), the lockup can be prevented with only the addition of a couple ICs.

5 References

The following documents were used as a reference for this application note:

1. Texas Instruments, *TPS65217x Single-Chip PMIC for Battery-Powered Systems data sheet*
2. Texas Instruments, *TPS65217 EVM user's guide*
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, INDIRECT, 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/sampterms.htm).