

Designing Robust TPS65217 Systems for V_{IN} Brownout

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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.

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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

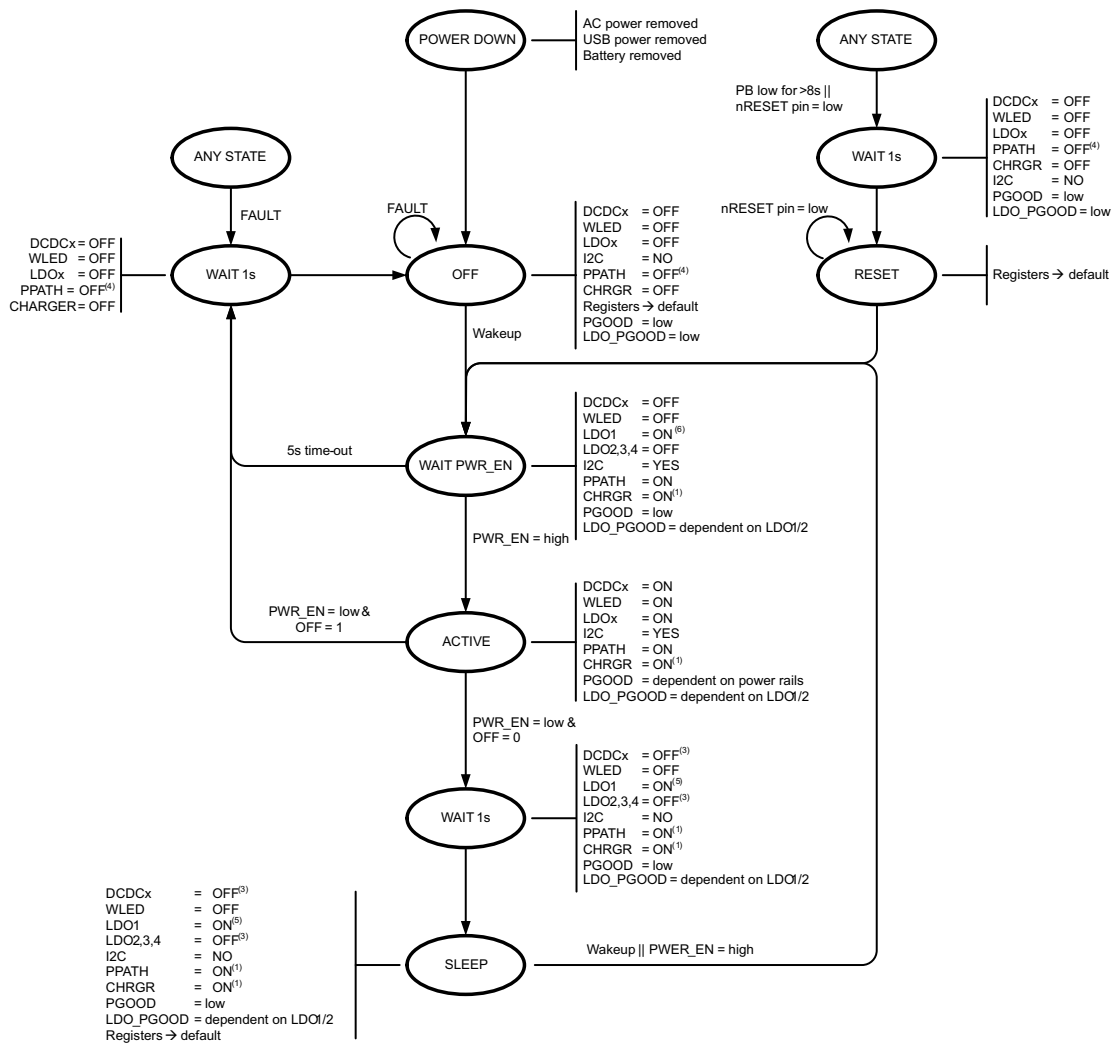
Implementing any one of the nonideal applications of the TPS65217 device puts the system at risk of experiencing a lockup as a result of a brownout condition on the input voltage. The solution circuits provided in this application report are for preventing a lockup when the suggested usage cannot be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



NOTES:

Wakeup = $V_{USB}(\uparrow) \parallel V_{AC}(\uparrow) \parallel PB(\downarrow)$ || Returning from RESET state| SEQUP bit= 1
 FAULT = $LVLO \parallel OTS \parallel PGOOD \text{ low} \parallel PWR_EN \text{ pin not asserted within } 5s \text{ of Wakeup event}$
 If no battery is present OVP on AC input also leads to OFF mode. With battery present device switches automatically from AC to BAT if AC is >6.5V and back to AC when voltage recovers to >6.5V.
 Device will remain in RESET state for at least 1s.
 Sequencer is triggered when entering ACTIVE state

(1) Only if USB or AC supply is present
 (3) All rails not controlled by the sequencer maintain state when entering SLEEP mode, i.e. they will not be powered down when entering SLEEP mode
 (4) Battery voltage always supplies the system (SYS pin)
 (5) LDO1/2 are not powered down when entering SLEEP mode if assigned to STROBE 14/15 or not under sequencer control. In SLEEP mode, LDO1 and 2 can source 100µA only. By default LDO1 is assigned to STROBE15 and LDO2 to STROBE2.
 (6) LDO1 and/or LDO2 are powered up if assigned to STROBE 14/15. By default LDO1 is assigned to STROBE15 and LDO2 to STROBE2.

Figure 1. TPS65217 Global State Diagram

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_{IN} .

2 Application Overview

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

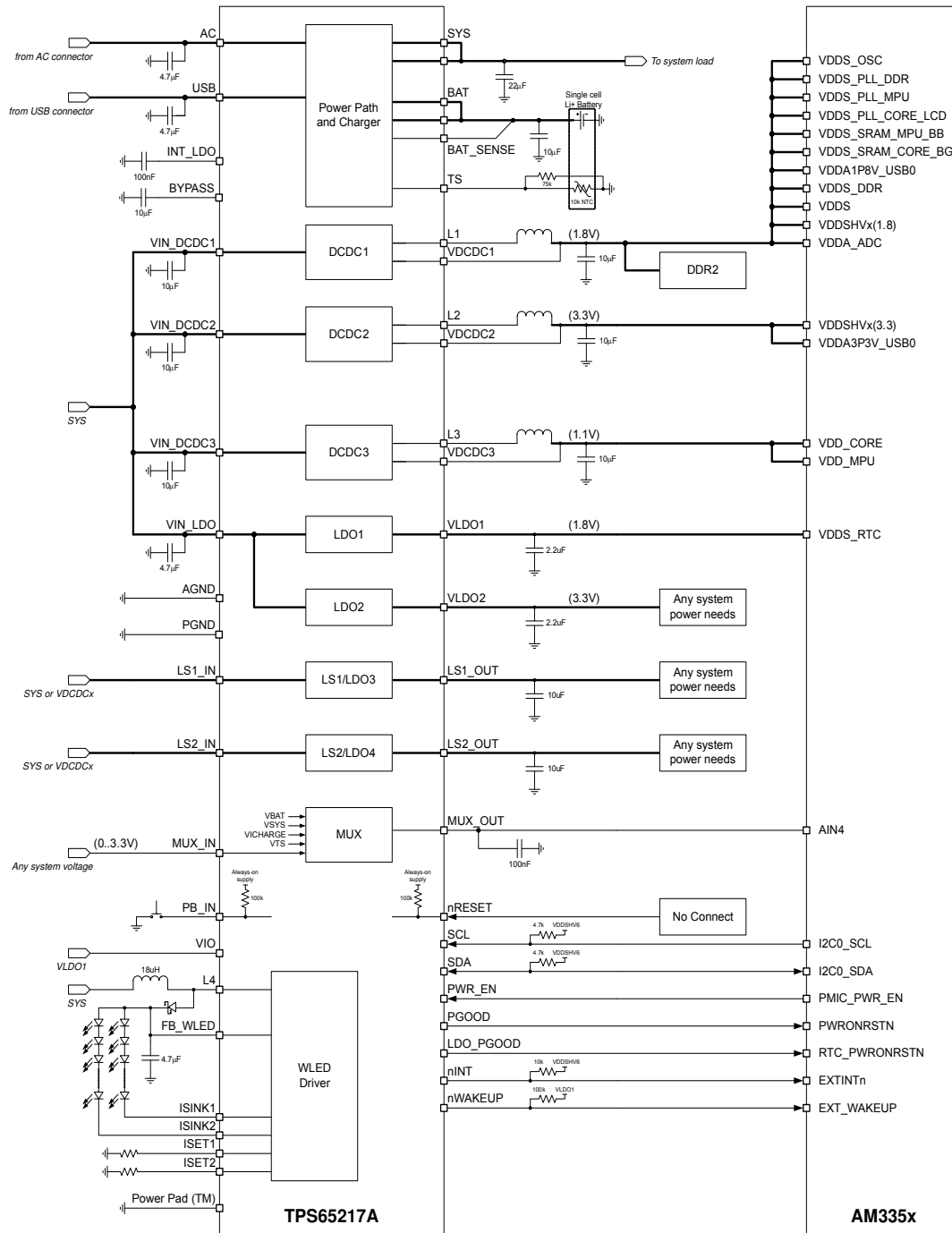
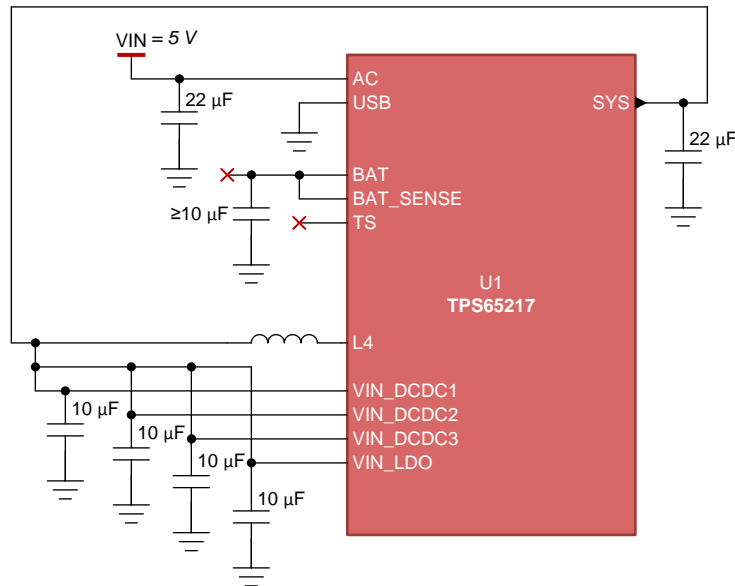


Figure 2. TPS65217 Typical Application Circuit

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.



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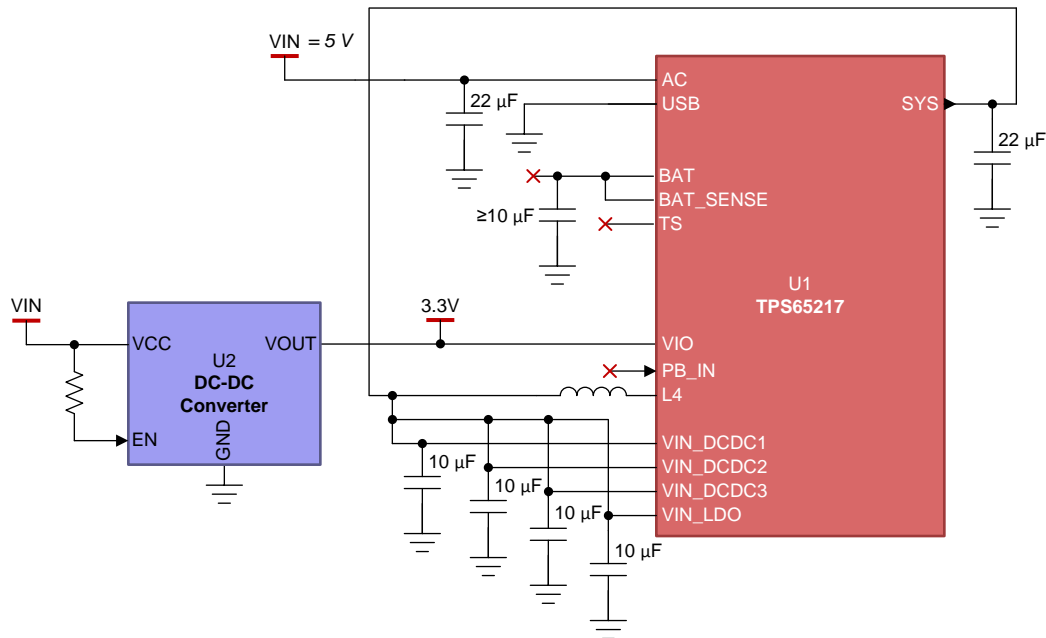
Figure 3. TPS65217 Application Case A

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.



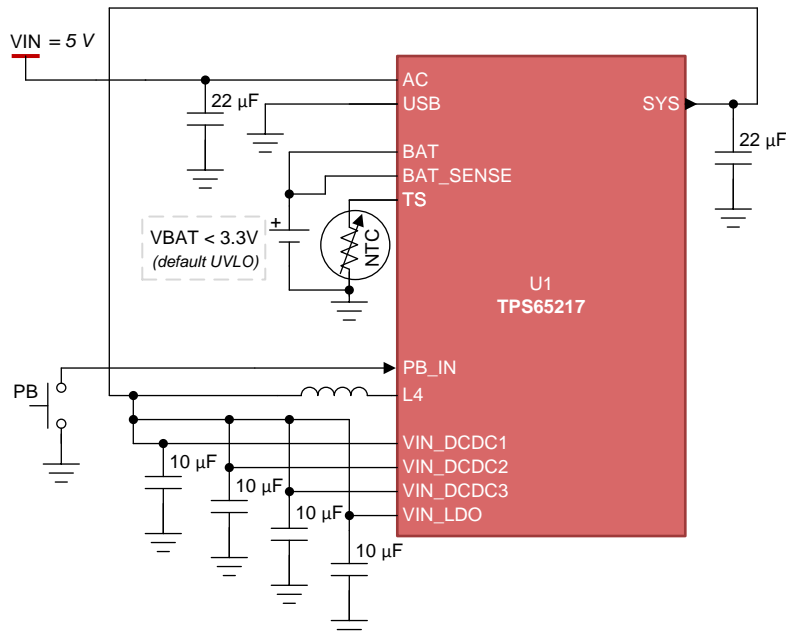
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Figure 4. TPS65217 Application Case B

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.



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Figure 5. TPS65217 Application Case C

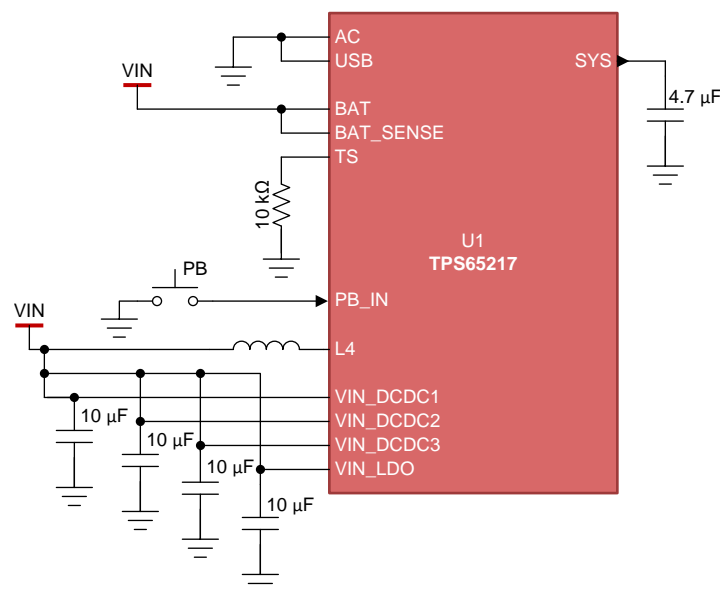
If a brownout occurs on the V_{IN} voltage for <1 s when the voltage on the battery (VBAT pin) is below the undervoltage lockout (UVLO) set point, a lockup can still occur even though Case C closely resembles the ideal application circuit. Fortunately, this lockup can also be avoided with a robust solution 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)



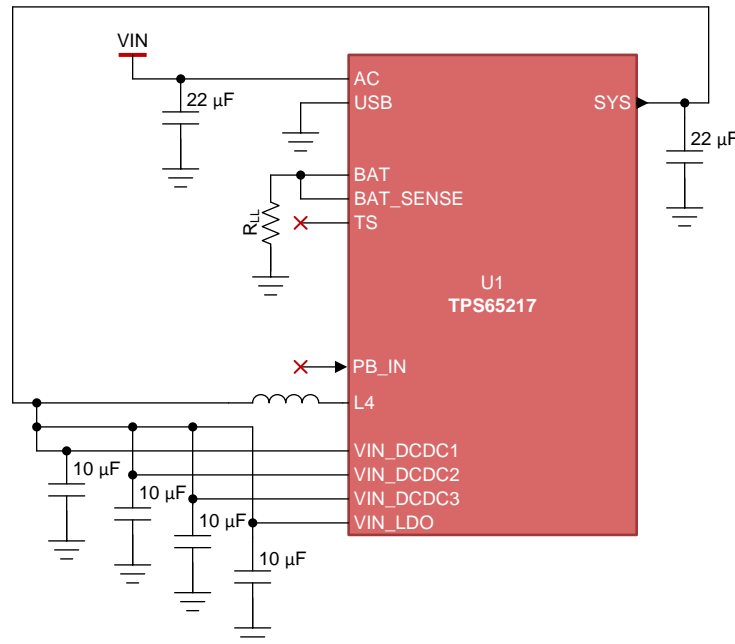
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Figure 6. Solution Circuit Number 1

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.

3.2 Solution Circuit Number 2 for Case A (No Battery)

When no battery is used in the system and $V_{IN\ max} \geq 5.5\ V$, V_{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_{LL}) connected from the BAT pin to GND, to replace the capacitor normally recommended in the design.



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Figure 7. Solution Circuit Number 2

Connecting a large bypass capacitor (>10 μF) to the BAT pin essentially provides a very small battery for the system. This capacitor is not 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.

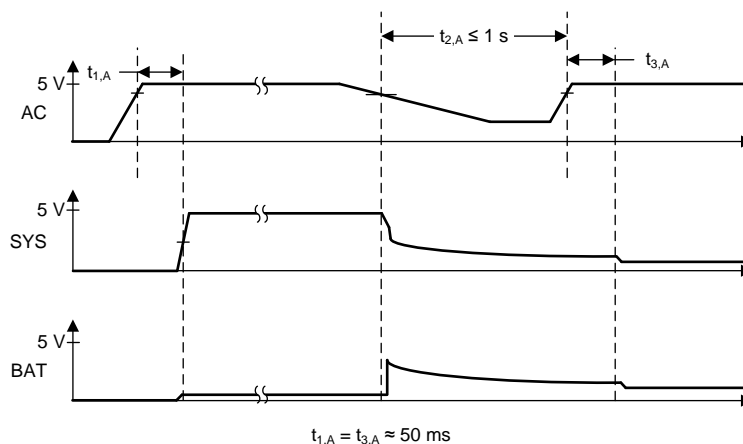


Figure 8. TPS65217 Lockup Condition Without a Battery Because of Capacitance on VBAT

To resolve this issue, a light-load resistor ($R_{LL} = 1\ k\Omega$ to $10\ k\Omega$) 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_{IN} without any lockup behavior.

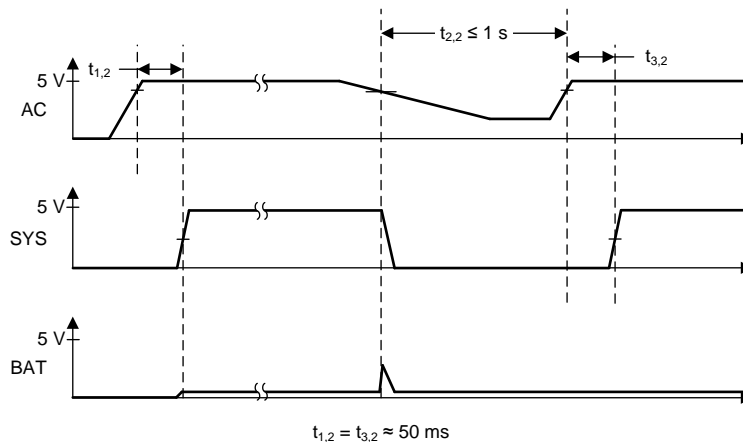
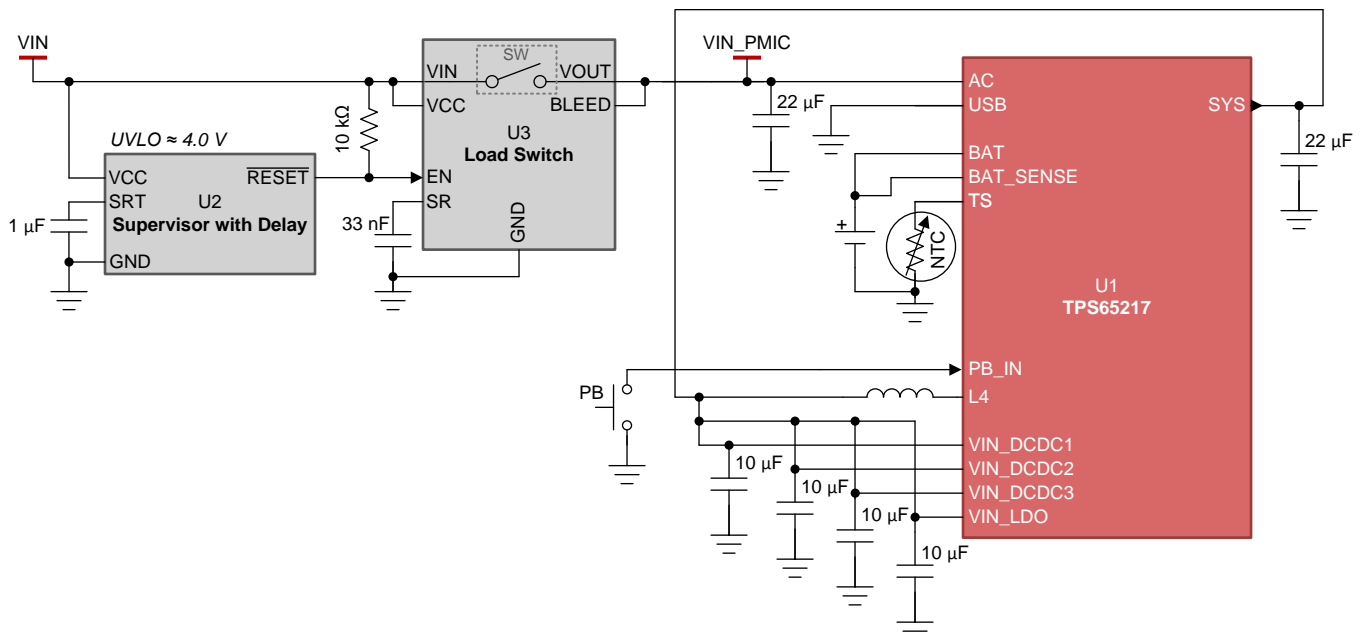


Figure 9. TPS65217 VIN Brownout Recovery With Solution Circuit Number 2

3.3 Solution Circuit Number 3 for Case B and Case C



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Figure 10. Solution Circuit Number 3

Figure 11 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_{BAT}) does not continue to discharge during the brownout condition on V_{IN} (directly connected to AC). When V_{IN} drops below the $UVLO_{PMIC}$ 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.

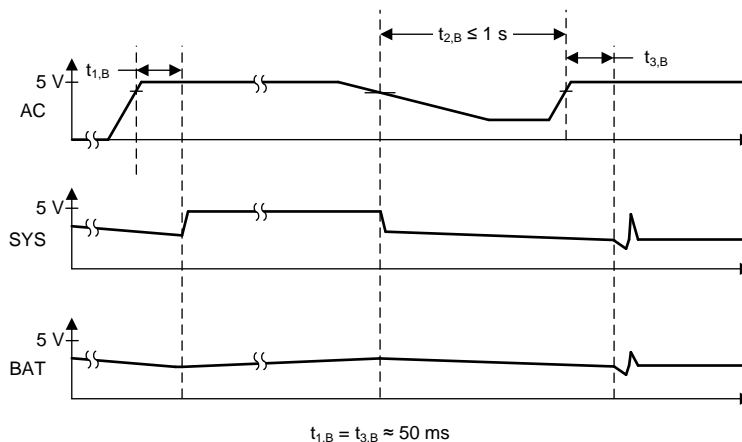


Figure 11. TPS65217 Lockup Condition With a Battery Because of PPATH Changeover

Avoiding a lockup can only be achieved by preventing the brownout on V_{IN} upstream from the TPS65217 device. Solution circuit number 3 implements an external supervisor with a delay timer controlling a load switch when $UVLO_{EXT} > UVLO_{PMIC}$ and $t_{delay} \geq 2$ 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_{IN} when the supervisor circuit senses a $UVLO_{EXT}$ condition. The supervisor disables the load switch from the AC pin and the supervisor does not re-enable the load switch until V_{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_{IN} is reapplied through the load switch.

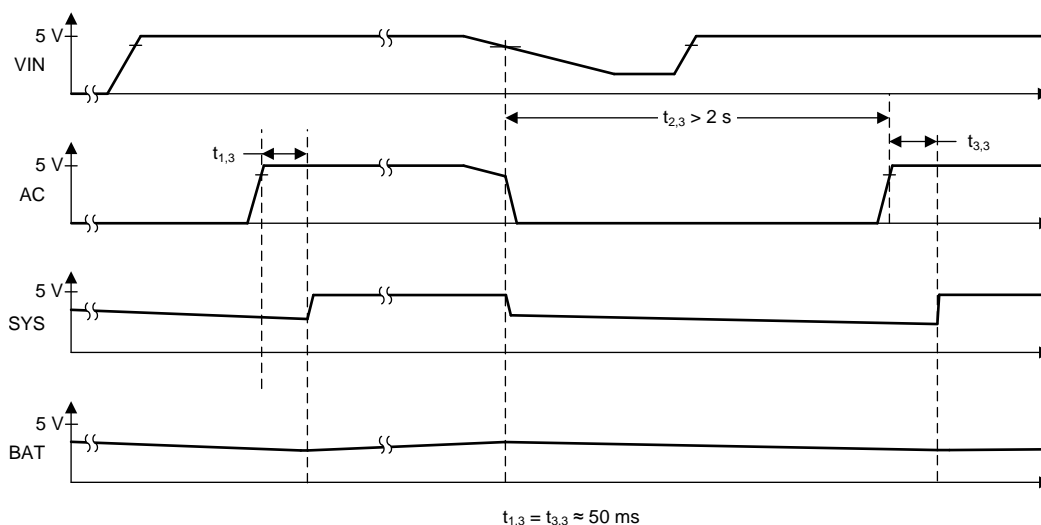


Figure 12. TPS65217 V_{IN} Brownout Recovery With Solution Circuit Number 3

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](#)

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