Application Report
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How to Power the TPS6507x On and Off

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ABSTRACT

The TPS6507x is a single-chip power management solution for portable applications. The chip contains a battery charger, three step-down converters, two low-dropout regulators (LDO), a wLED boost converter, an I^2C™ interface, a 10-bit A/D converter, and a touch-screen interface. Power-path management allows the USB, AC adaptor, or battery input to power the device. The TPS6507x features a flexible start-up and shut-down sequence, depending on customer configuration and on the dominant power source. This application report explains the TPS6507x state machine, describes four different examples of turning the TPS6507x outputs on and off, and corrects some common misconceptions.

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1 Introduction

The TPS6507x is a single-chip power solution that includes a single cell Li-Ion or Li-Polymer battery charger as well as a power-path-management system. The charger is supplied by an AC adapter or USB power source. The device can also be powered by the battery if no power is available at the AC adapter or USB inputs. The method used to turn the device outputs on and off varies depending on which way the device is powered. Some methods require specific timing. In these cases, the TPS6507x is used in conjunction with an application processor. If a simpler system is desired, Case C, (Section 4.3 in the examples) shows an option of turning the device outputs on and off without using an application processor. The flexible nature of the turn-on scheme allows adaptation of the TPS6507x to various applications. Figure 1 shows a block diagram of the TPS6507x connected to the application processor. It shows the important input and output signals used in the turn-on and turn-off processes.

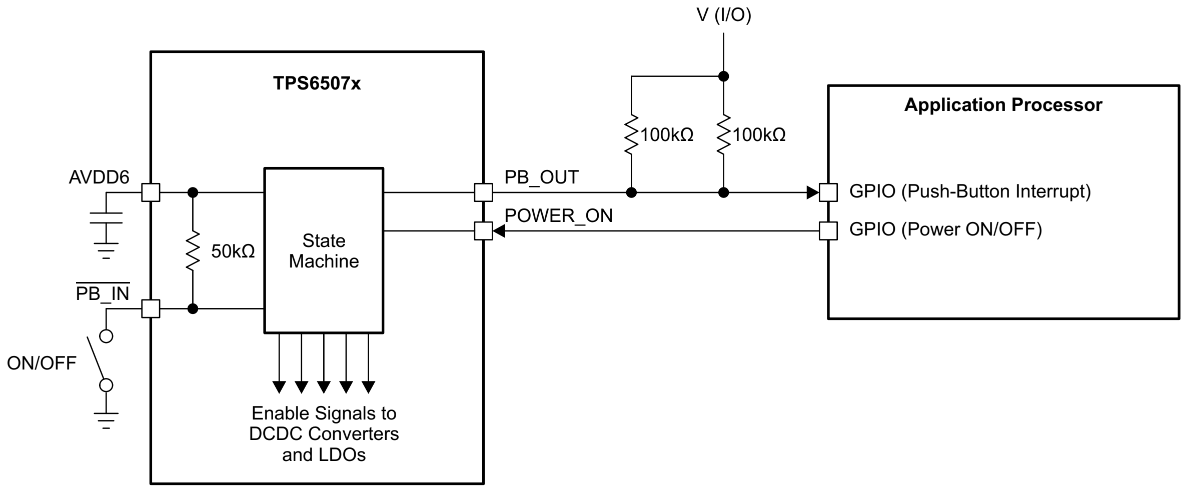

Figure 1. Block Diagram of TPS6507x and Application Processor System

2 Signal Definitions

The important TPS6507x signals for this application used throughout this document are as follows:

PB_IN: This is a user input that is implemented using a push-button. This signal in conjunction with POWER_ON going high turns the device off and on.

PB_OUT: This is an output signal from the TPS6507x that should be sent to the application processor. This signal is a level shifted and debounced version of PB_IN. It lags 50 ms behind PB_IN on the falling edge, and does not lag at all on the rising edge of PB_IN.

SYS: This is the system voltage, the output of the power-path manager.

POWER_ON: This is an input to the TPS6507x from the application processor. It also serves as an enable signal. Please note that this is different from the “Power ON 1” and “Power ON 2” states introduced later.

Converter x: The step-down converters start-up sequence is programmable via the CON_CTRL1 register. For most configurations, the three converters are separated into two groups. All converters within each group start at the same time. The converter x signal shows how one of these groups starts-up.

Converter y: This signal shows how the second group starts-up.

EN_DCDC1, EN_DCDC2, EN_DCDC3: These are the enable signals for the 3 DC/DC converters. The enables are assumed to happen at the same time as the signals “converter x” and “converter y” in the figures below.

PGOOD: This signal becomes active when all of the monitored converters (defined in the register PGOODMASK) are within minimum regulation.

AC: This signal is the voltage level at the AC adapter input. The AC pin would be connected to a DC power supply. For the purposes of turning on the TPS6507x, the USB voltage input causes exactly the same effect as the AC input.

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NOTE: The two LDOs are also included in the TPS6507x start-up sequence. Depending on how the register LDO_CTRL1 is set, they can ramp up at the same time as the step-down converters, after the step-down converters, or before the step-down converters. These LDO signals are not shown in the waveforms in this paper, but behave the same as the converter x and y signals.

3 State Machine

The state machine[1] shown in Figure 2 is helpful when attempting to visualize the start-up and shut-down procedures.

(1) The state machine shown in Figure 2 is a slight modification of the state machine found on pg. 34 of the TPS6507x datasheet (SLVA418)

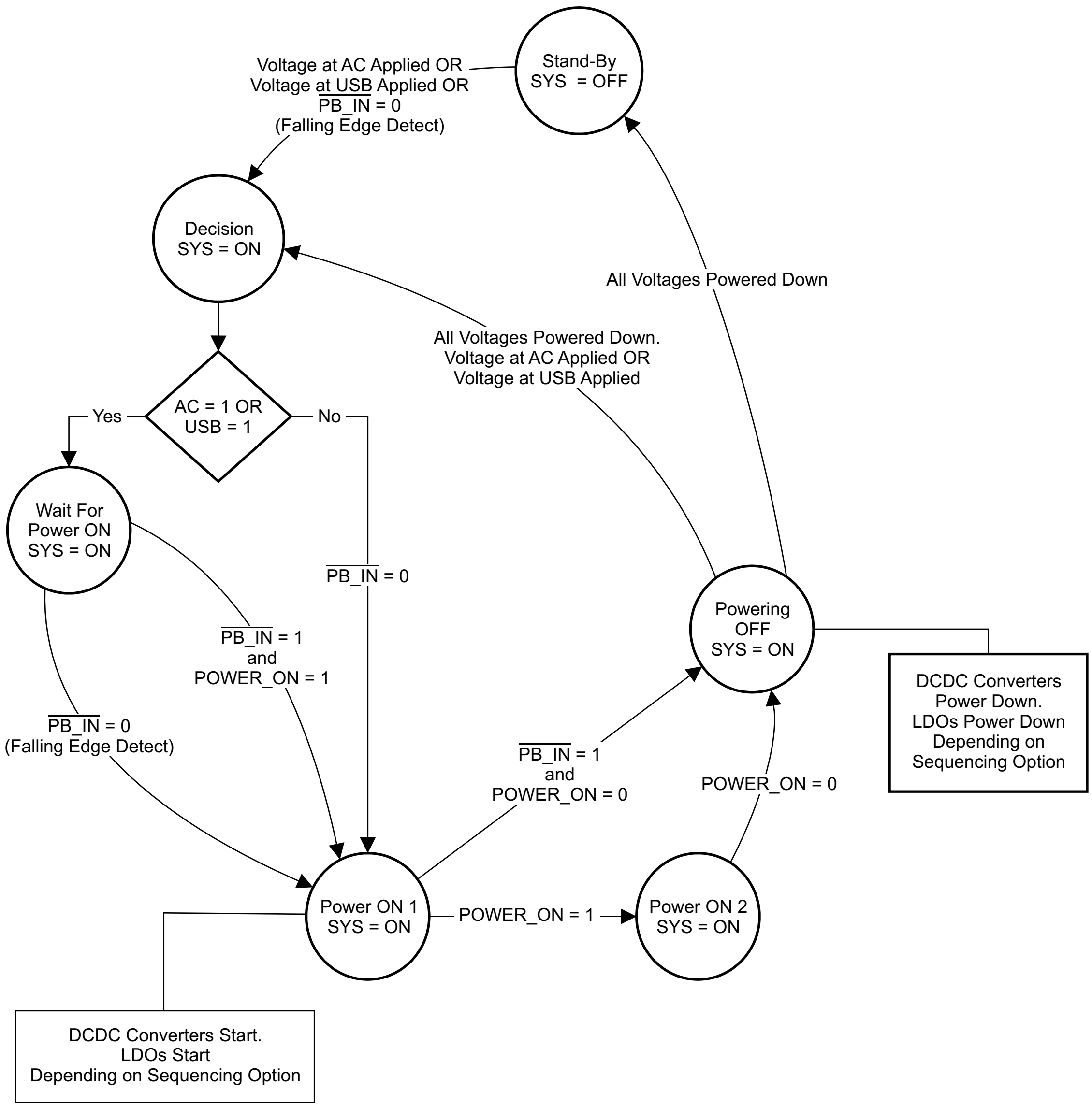

Figure 2. State Machine

The purpose of the "Stand-By" state is to allow for an option where the power consumption is dropped as far as possible without completely turning the device off. To achieve this low-power consumption, all of the step-down converters and SYS outputs are turned off. When in the "Stand-By" state, the TPS6507x can draw as little as 7 µA from the battery. When power is applied through the AC or USB inputs, it is not possible to stay in the "Stand-By" state.

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The “Decision” state is a transition state. Once the TPS6507x enters this state it immediately transitions to either the “Wait for Power ON” or “Power ON 1” state, depending on if AC/USB or battery power is used.

The two “Power ON” states reflect the two options for keeping the TPS6507x on. “Power ON 1” is the state used if PB_IN is being held low to keep the device on. Once POWER_ON is asserted high, the device transitions to the “Power ON 2” state, where the POWER_ON signal dictates when the TPS6507x transitions to the “Powering OFF” state.

Notice that the TPS6507x behaves differently depending on whether it is powered from the BAT, AC, or USB input. The state machine behaves the same if either the AC or USB input is used. If the BAT input is used, slightly different behavior occurs. The four examples, Cases A through D (Section 4.1 through Section 4.4 in the Examples section), help explain this state machine. Cases A and B show possible timing diagrams if the TPS6507x is powered only from the battery. Cases C and D show possible timing diagrams if the TPS6507x is powered from the AC or USB input.

4 Examples

4.1 *Case A:*

Figure 3 shows Case A, where the device is powered only from the battery and the PB_IN signal is used to turn the device on and off. A detailed description of Case A’s behavior is included after Figure 3.

A summary of the steps that occur in Case A are shown in Table 1.

Table 1. Case A Timing Diagram Description

SEQUENCE OF EVENTS	STATE
1. Systems starts with PB_IN = HIGH and all outputs off	Stand-By
2. PB_IN = LOW	Decision
	Power ON 1
3. SYS ramps up	Power ON 1
4. PB_OUT signal indicates to the processor that the PB_IN key has been pressed	
5. Converters ramp up	
6. PGOOD is turned on	
7. Processor sets POWER_ON = HIGH (keeps TPS6507x enabled)	Power ON 2
8. PB_IN is released HIGH	
9. PB_IN is set LOW again	
10. PB_OUT signal indicates to the processor that the PB_IN key has been pressed	
11. Processor sets POWER_ON = LOW	Powering OFF
12. Converters ramp down with the inverse sequencing and PGOOD is turned off	
13. SYS voltage ramps down	Stand-By
14. TPS6507x enters “Stand-By” state while PB_IN is still held LOW	
15. PB_IN is released HIGH	

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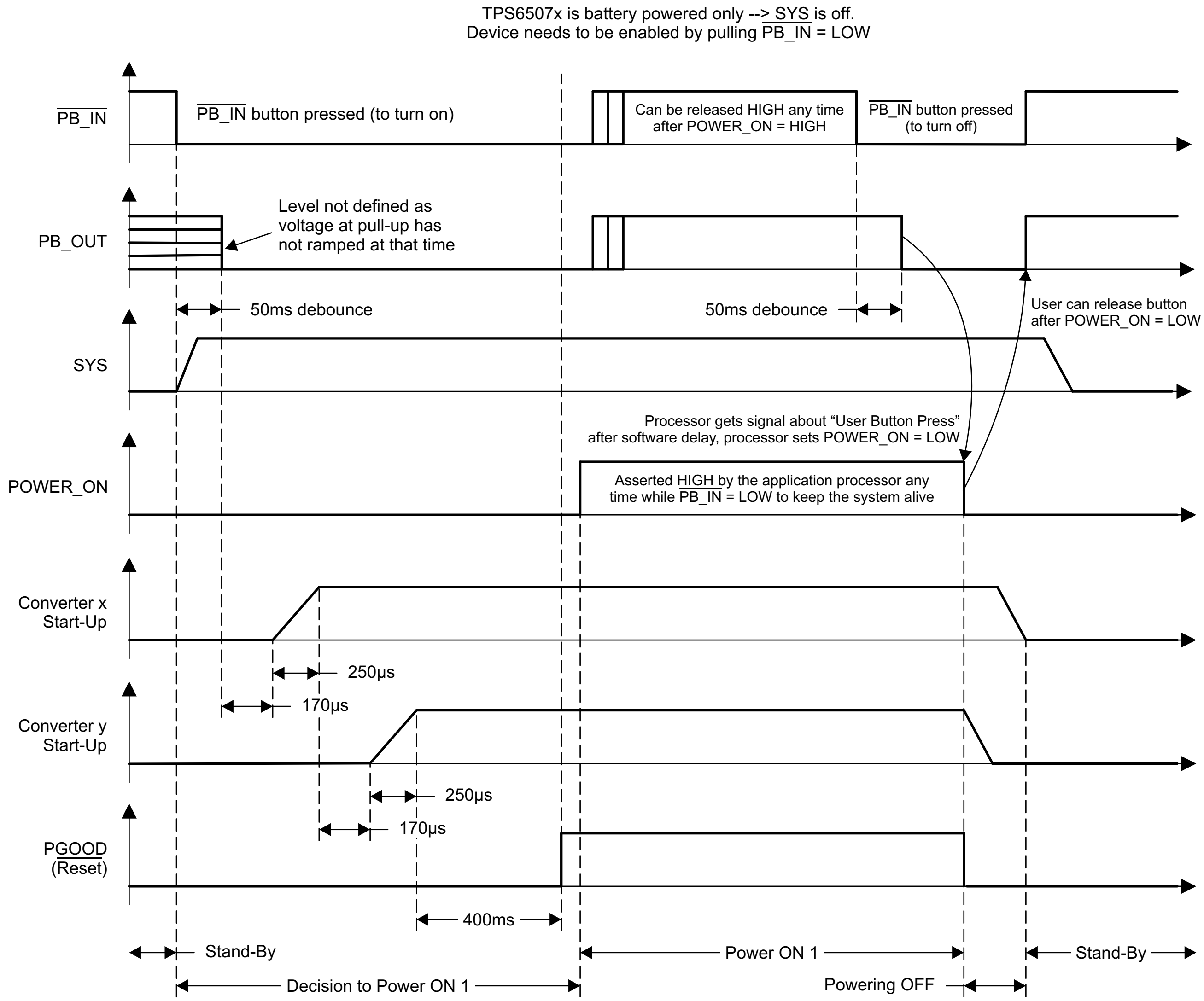

Figure 3. Case A - Battery Powered (No AC or USB Input Voltage)

When in this configuration, the PB_IN pin dictates when the start-up sequence begins. The PB_IN signal is easily controlled by installing a push-button. The PB_OUT signal is an output of the TPS6507x and is a level shifted and debounced version of the PB_IN signal. The debouncing causes a 50-ms delay between PB_IN and PB_OUT on the falling edge. As soon as PB_IN is pulled low, the TPS6507x leaves the "Stand-By" state and enters the "Power ON 1" state, where the SYS voltage starts to ramp up. Once the SYS voltage is stabilized, the converters start to turn-on, depending on the configured start-up sequence. Once all of the converters are turned on, the PGOOD signal output goes high.

The PB_OUT signal is sent to the application processor, which in turn, sends a POWER_ON signal back to the TPS6507x. The POWER_ON signal must be set to logic high before the PB_IN button is released for the TPS6507x to stay on. The device transitions to the "Power ON 2" state once the POWER_ON signal is set to logic high. To turn the TPS6507x off, the user just has to push the PB_IN push-button again. 50 ms later the PB_OUT signal drops low, which signals the application processor to set the POWER_ON signal to logic low. As soon as the POWER_ON signal drops, the device transitions to the "Powering OFF" state and the converters start ramping down. The sequence in which they turn off is reversed from the sequence in which they turned on. The PGOOD signal pulls low as soon as the converters start to turn off. The SYS signal is the last to turn off. As soon as all of the voltages have turned off, the TPS6507x transitions to the "Stand-By" state.

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4.2 Case B

Figure 4 shows Case B, where the device is powered only from the battery, but the scheme used to turn off the device is slightly different from Case A. A detailed description of Case B's behavior is included after Figure 4.

A summary of the steps that occur inFigure 4 are shown in Table 2.

Table 2. Case B Timing Diagram Description

SEQUENCE OF EVENTS	STATE
1. Systems starts with $\overline{\text{PB\_IN}}$ = HIGH and all outputs off	Stand-By
2. $\overline{\text{PB\_IN}}$ = LOW	Decision
	Power ON 1
3. SYS ramps up	Power ON 1
4. PB_OUT signal indicates to the processor that the $\overline{\text{PB\_IN}}$ key has been pressed	
5. Converters ramp up	
6. PGOOD is turned on	
7. Processor sets POWER_ON = HIGH	Power ON 2
8. Processor sets POWER_ON = LOW	Powering OFF
9. Converters ramp down with the inverse sequencing and PGOOD is turned off	
10. SYS voltage ramps down	Stand-By
11. POWER_ON is set HIGH again	
12. No change in state; TPS6507x stays disabled until $\overline{\text{PB\_IN}}$ is released and pulled LOW again	
The TPS6507x converters can only be enabled with the falling edge of $\overline{\text{PB\_IN}}$ when powered from the battery input.	

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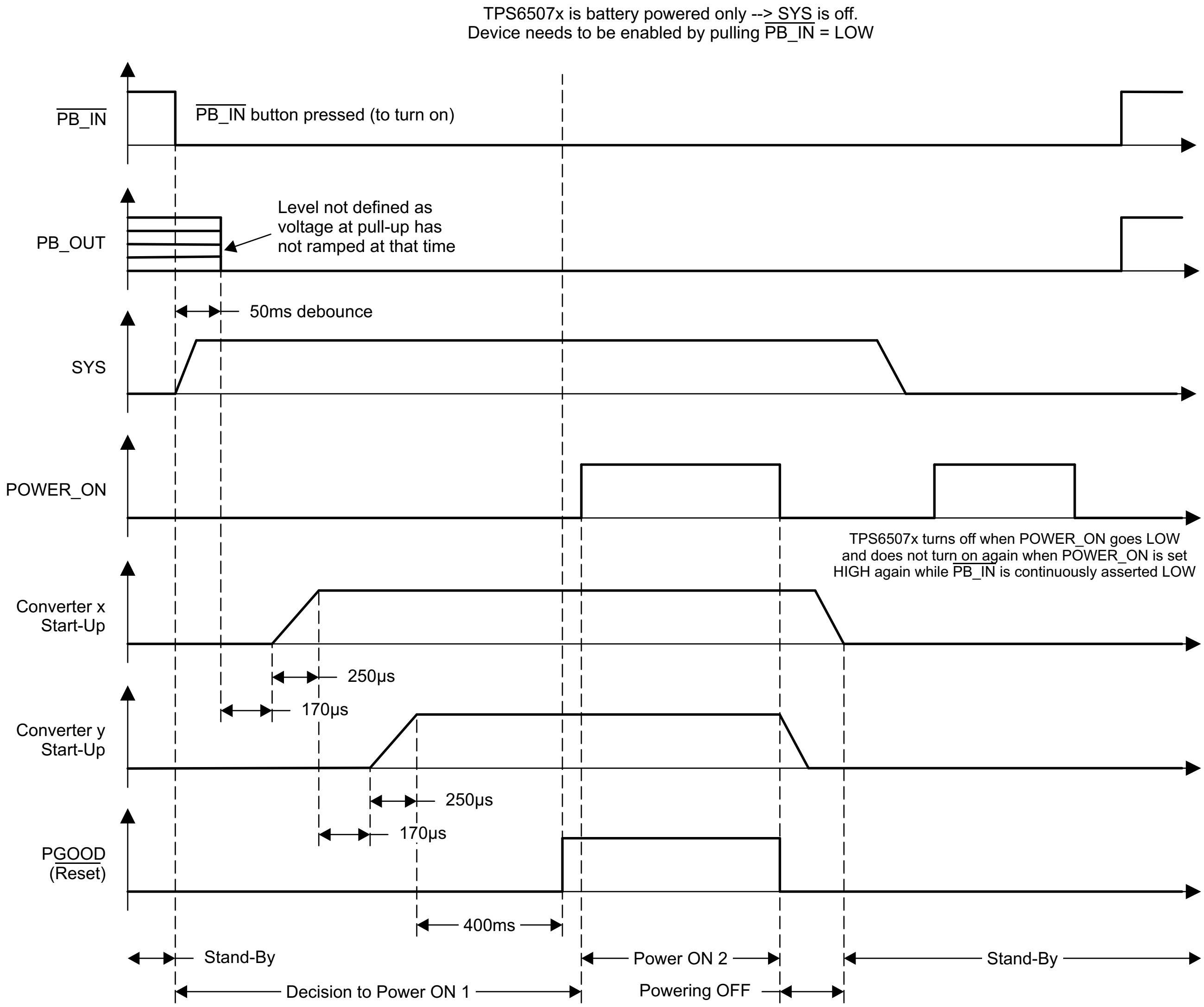

Figure 4. Case B - Battery Powered (No AC or USB Input Voltage)

This example shows that the device can only be enabled once each time the PB_IN push-button is pressed. The turn-on sequence is exactly the same as in Case A except that the PB_IN push-button is held down for the entire power cycle. Instead of using a second button press to turn off the device, the application processor turns off the POWER_ON signal. The falling edge of this signal transitions the device to the "Powering OFF" state, despite the fact that the PB_IN push-button is still pressed.

Once the device has been powered off and is in the "Stand-By" state, only the falling edge of PB_IN causes the device to transition to the "Decision" state. While in the "Stand-By" state, turning the POWER_ON signal back on does nothing.

4.3 Case C

Figure 5 shows Case C, where the AC or USB input is used to power the device and PB_IN is not toggled at all and is allowed to remain high with its internal pull-up resistor. This start-up sequence does not make use of PB_IN, so the converters are controlled only with POWER_ON. This means that the TPS6507x could be operated without a separate application processor. In the following set of waveforms, PB_OUT has a pull-up resistor connected to converter x; this is presented as an optional output to the application processor. A detailed description of Case C's behavior is included after Figure 5.

A summary of the steps that occur in Figure 5 are shown in Table 3.

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Table 3. Case C Timing Diagram Description

SEQUENCE OF EVENTS	STATE
1. Systems starts with everything off	Stand-By
2. V(AC) = 5 V	Decision
	Wait for Power ON
3. SYS ramps up; main state machine active	Wait for Power ON
4. POWER_ON = HIGH	Power ON 1
	Power ON 2
5. Converters ramp up	Power ON 2
6. PGOOD is turned on	
7. POWER_ON = LOW	
8. Converters ramp down in inverse sequence and PGOOD is turned off	Powering OFF
9. Converters ramp down with the inverse sequencing and PGOOD is turned off	
10. Steps 4 through 9 repeat	
The TPS6507x is enabled or disabled by POWER_ON while $\overline{\text{PB\_IN}}$ is inactive HIGH	

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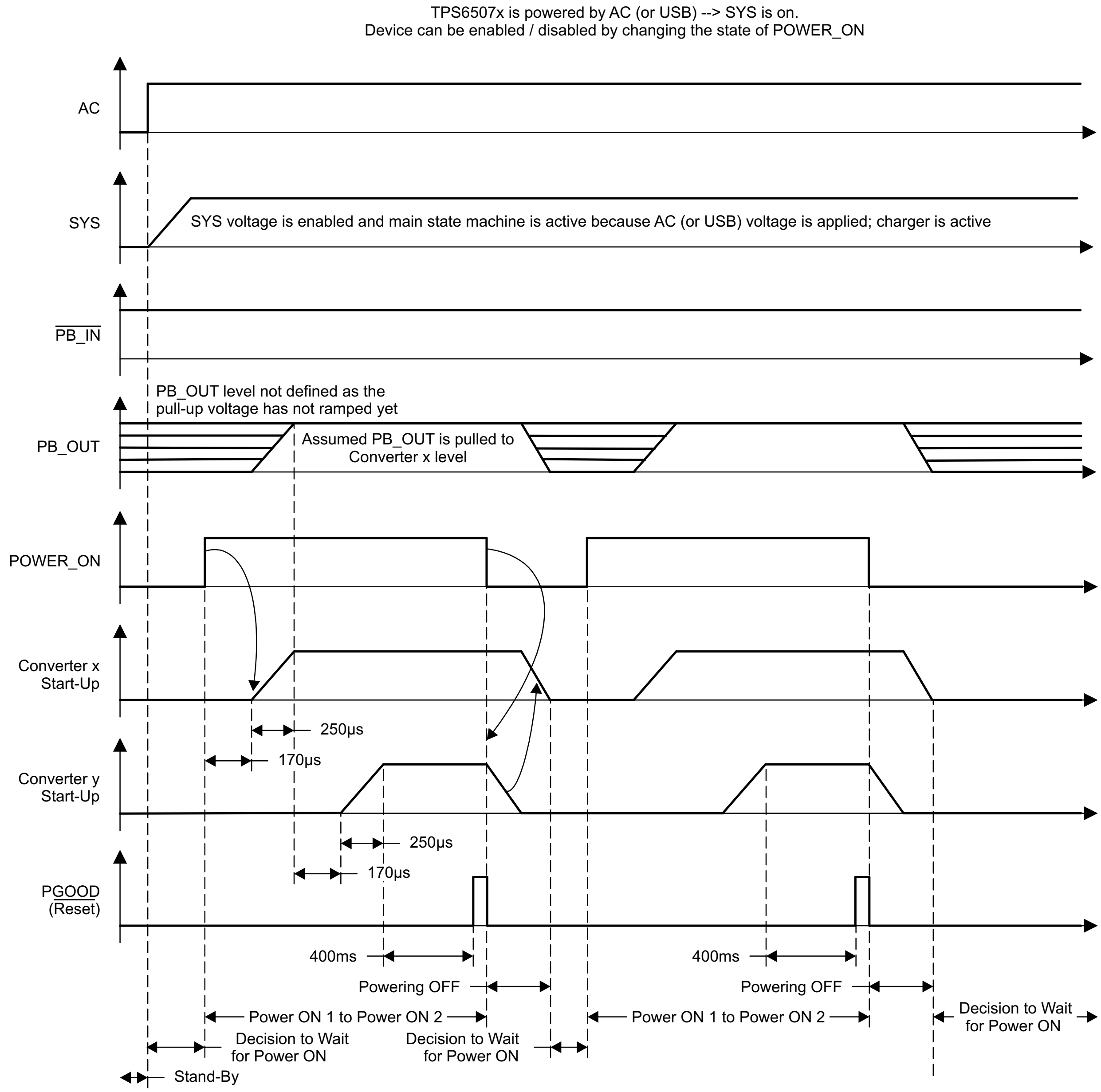

Figure 5. Case C – AC or USB Powered

In this configuration, PB_OUT is connected to converter x through a pull-up resistor. Because of this, PB_OUT follows the converter x voltage.

The first difference that should be noted from Cases A and B is that the $\overline{\text{PB\_IN}}$ input is not toggled at all, it is simply left high. Once 5 V is applied to the AC pin, the TPS6507x enters the “Decision” state and the SYS signal starts to ramp up. Next, the device transitions to the “Wait for Power ON” state.

POWER_ON is raised high at some point after SYS has turned on. Once POWER_ON has been raised to logic high, the device transitions to the “Power ON 1” state, where the converters start to turn on in a particular sequence. Once the converters have completely turned on, the PGOOD signal turns on. Since the POWER_ON signal is logic high, the TPS6507x immediately transitions to the “Power ON 2” state. From there, the system remains on until something changes. Pulling the POWER_ON pin low causes the device to transition to the “Powering OFF” state, where the converters and PGOOD signals turn off. After everything is off, the device transitions to the “Decision” state, and then to the “Wait for Power ON” state. From here, the entire cycle repeats.

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When the AC or USB input powers the TPS6507x and the $\overline{\text{PB\_IN}}$ input is left high, the step-down converters are controlled with the POWER_ON signal. Notice that the SYS output remains high the entire time, which is true whenever there is power applied at the AC or USB input.

4.4 Case D

Figure 6 shows Case D, where the AC or USB input is used to power the device and the $\overline{\text{PB\_IN}}$ signal is used to turn the device on. A detailed description of Case D's behavior is included after Figure 6.

A summary of the steps that occur in Figure 6 are shown in Table 4.

Table 4. Case D Timing Diagram Description

SEQUENCE OF EVENTS	STATE
1. Systems starts with everything off	Stand-By
2. V(AC) = 5 V	Decision
	Wait for Power ON
3. SYS ramps up	Wait for Power ON
4. $\overline{\text{PB\_IN}}$ = LOW	Power ON 1
5. Converters ramp up	
6. PGOOD is turned on	
7. POWER_ON = HIGH	Power ON 2
8. POWER_ON = LOW disables converters	Powering OFF
9. Converters ramp down and PGOOD is turned off	Powering OFF
	Decision
	Wait for Power ON
10. POWER_ON is set HIGH again	Wait for Power ON
11. No change in state; TPS6507x stays disabled until $\overline{\text{PB\_IN}}$ is released	

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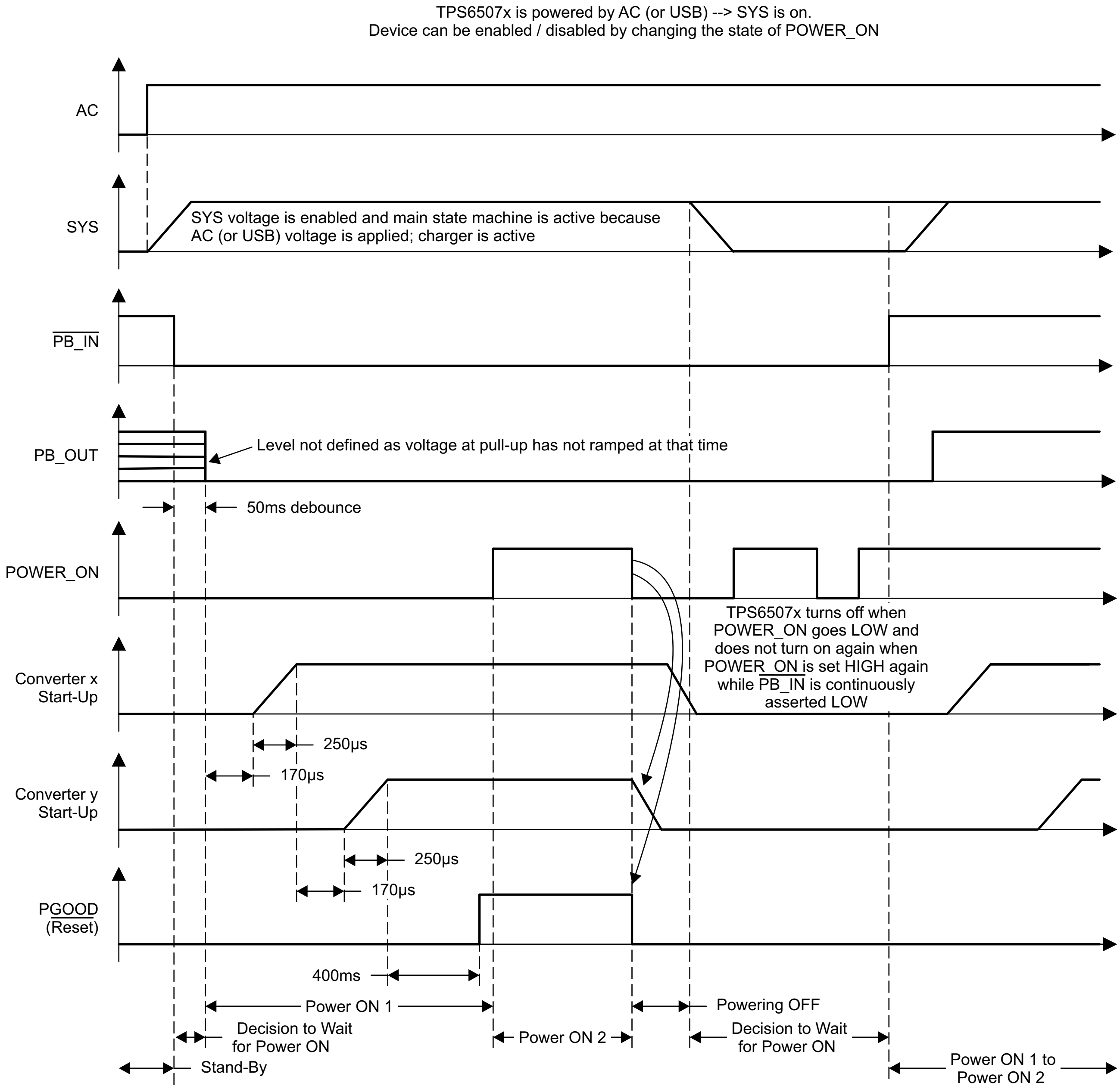

Figure 6. Case D – AC or USB Powered

As in Case C, the TPS6507x is powered by the AC or USB pins. Likewise, the SYS signal starts to ramp-up as soon as the input power is applied. Now, instead of using the POWER_ON pin to turn on the converters, the PB_IN button is used.

When the push-button is pressed, the PB_IN signal goes low, signaling the device to enter the "Power ON 1" state. This signals the converters to start their turn-on sequence. Once all of the converters have turned on, the PGOOD signal turns on. At some point during this process, the POWER_ON signal is turned on by the application processor. As soon as the POWER_ON signal is activated, the TPS6507x transitions to the "Power ON 2" state. When the application processor switches the POWER_ON signal to logic low, the device enters the "Powering OFF" state, and the converters and the PGOOD signal start to ramp down. Once the output signals have turned off, except for the SYS output, the device enters the "Decision" state and then almost immediately enters the "Waiting for Power ON" state.

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While in the “Waiting for Power ON” state, further toggling of the POWER_ON signal does nothing because $\overline{PB\_IN}$ is continuously held low. When $\overline{PB\_IN}$ is raised to logic high, the TPS6507x transitions to the “Power ON 1” state because the condition of having both $\overline{PB\_IN}$ and POWER_ON logic high is true. The device then transitions to the “Power ON 2” state since POWER_ON is already logic high.

5 POWER_ON Pin Timing

Figure 7 and Figure 8 illustrate that the POWER_ON pin must be held low for a minimum amount of time before the TPS6507x transitions to the “Powering OFF” state. Both of the following figures occur when the device is battery powered.

In Figure 7, the POWER_ON signal is toggled low, but not for long enough to trigger the transition from the “Power ON 2” state to the “Powering OFF” state.

Figure 7. POWER_ON Fails to Trigger “Powering OFF” State

In Figure 8, the POWER_ON signal is held low for slightly longer; just long enough for the “Power ON 2” state to transition to the “Powering OFF” state. The PGOOD signal is pulled low as soon as the “Powering OFF” state is reached; however, it is only actively pulled low for a short period of time, after which the PGOOD signal is pulled up to the declining pull-up voltage.

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Figure 8. POWER_ON Triggers "Powering OFF" State, PGOOD and SYS Signals Start to Ramp Down

The behavior outlined here is used to correctly turn on and off the TPS6507x. Page 69 of the TPS6507x datasheet (SLVA418) outlines the different types of TPS6507x devices and the possible application processors that are used with each. It also shows the default output voltages for each device as well as suggested timing settings.

6 Summary

Most of the behavior described in this application note can be inferred by examining the state machine and taking into account the delays associated with each signal. Slightly different behavior occurs, depending on how the TPS6507x is powered. When powered from the battery, the device is capable of implementing a power-saving state, the "Stand-By" state, where all of the outputs are turned off. When powered from the AC or USB input, this power-saving state is unreachable, and the SYS output is always on. If necessary, the TPS6507x can be configured to operate without an application processor, but only if the battery input is not used as a source of power. The TPS6507x is a versatile power solution allowing the configuration of the start-up and shut-down sequences to fit different applications.

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