



# TPS65381A-Q1 Multirail Power Supply for Microcontrollers in Safety-Relevant Applications

## 1 Device Overview

### 1.1 Features

- **Qualified for Automotive Applications**
- **AEC-Q100 Qualified With the Following Results:**
  - Device Temperature Grade 1: –40°C to +125°C Ambient Operating Temperature
  - Device HBM ESD Classification Level H2
  - Device CDM ESD Classification Level C3B
- **Multirail Power Supply Supporting Among Others**
  - TI Hercules™ TMS570, C2000™, and Various Functional-Safety Architecture Microcontrollers
- **Supply Rails**
  - Input voltage range:
    - 5.8 V to 36 V (CAN, I/O, MCU Core, and Sensor-Supply Regulators Functional)
    - 4.5 V to 5.8 V (3.3 V I/O and MCU Core Regulators Functional)
  - 6-V Asynchronous Switch Mode Preregulator With Internal FET, 1.3-A Output Current
  - 5-V (CAN) Supply Voltage, Linear Regulator With Internal FET, 300-mA Output Current
  - 3.3-V or 5-V (MCU I/O) Voltage, Linear Regulator With Internal FET, 300-mA Output Current
  - 0.8-V to 3.3-V Adjustable (MCU Core Voltage), Linear Regulator Controller With External FET
  - 3.3-V to 9.5-V Adjustable Sensor Supply: Linear Tracking Regulator With Internal FET, 100-mA Output Current, and Protection Against Short-to-Supply and Short-to-Ground
  - Charge Pump: Typically 12 V Above Battery Voltage
- **Power Supply and System Monitoring**
  - Independent Undervoltage and Overvoltage Monitoring on All Regulator Outputs, Battery Voltage, and Internal Supplies
  - Independent Voltage References for Regulator References and Voltage Monitoring. Voltage-Monitoring Circuitry With Independent Bandgap Reference and Separate Supply Input Pin
  - Self-Check on all Voltage Monitoring (Automatic During Power-Up and After Power-Up Initiated by External MCU)
  - All Supplies With Internal FETs Protected With Current-Limit and Overtemperature Shutdown
- **Microcontroller (MCU) Interface**
  - Watchdog: Trigger Mode (OPEN/CLOSE Window) or Question and Answer Mode
  - MCU Error-Signal Monitor For Lock-Step Dual-Core MCUs Including Hercules™ TMS570, C2000™, and Various Functional-Safety Architecture MCUs Using Pulse-Width Modulation (PWM) Error Output
  - DIAGNOSTIC State for Performing Device Self-Tests, Diagnostics, and External Interconnect Checks
  - SAFE State for Device and System Protection on Error Event Detection
  - Clock Monitor for Internal Oscillator
  - Self-Tests for Analog- and Digital-Critical Circuits Executed With Every Device Power Up or Activated by MCU in DIAGNOSTIC State
  - CRC on Nonvolatile Memory, Device and Configuration Registers
  - Reset Circuit and Output Pin for MCU
  - Diagnostic Output Pin Allowing MCU to Observe Through a Multiplexer Internal Analog and Digital Signals of the Device
- **Serial Peripheral Interface (SPI)**
  - Configuration Registers
  - Watchdog Question and Answers
  - Diagnostic Status Readout
  - Compliant With 3.3-V and 5-V Logic Levels
- **Enable Drive Output for Disabling Safing-Path or External Power-Stages on Detected System-Failure**
- **Wakeup Through IGNITION Pin or CAN WAKEUP Pin**
- **Package: 32-Pin HTSSOP PowerPAD™ IC Package**



## 1.2 Applications

### • Safety Automotive Applications

- Power Steering: Electrical Power Steering (EPS) and Electro Hydraulic Power Steering (EHPS)
- Braking: Anti-Lock Brake System (ABS), Electronic Stability Control (ESC), and Electric Parking Brake
- Advanced Driver Assistance Systems (ADAS)
- Suspension

### • Industrial Safety Applications

- Safety Programmable-Logic Controllers (PLCs)
- Safety I/O Control Modules
- Test and Measurement
- Railway and Subway Signal Control and Safety Modules
- Elevator and Escalator Safety Control
- Wind Turbine Control

## 1.3 Description

The TPS65381A-Q1 device is a multirail power supply designed to supply microcontrollers (MCUs) in safety-relevant applications, such as those found in automotive and industrial markets. The device supports Texas Instruments' Hercules™ TMS570 MCU and C2000™ MCU families, and various other MCUs with dual-core lockstep (LS) or loosely-coupled architectures (LC).

The TPS65381A-Q1 device integrates multiple supply rails to power the MCU, controller area network (CAN), or FlexRay, and an external sensor. An asynchronous-buck switch-mode power-supply converter with an internal FET converts the input supply (battery) voltage to a 6-V preregulator output. This 6-V preregulator supplies the other regulators. The device supports wakeup from IGNITION or wakeup from the CAN transceiver.

The integrated, fixed 5-V linear regulator with internal FET can be used for a CAN or FlexRay transceiver supply for example. A second linear regulator, also with an internal FET, regulates to a selectable 5-V or 3.3-V output which, for example, can be use for the MCU I/O voltage.

The TPS65381A-Q1 device includes an adjustable linear-regulator controller, requiring an external FET and resistor divider, that regulates to an adjustable voltage of between 0.8 V and 3.3 V which may be used for the MCU core supply.

The integrated sensor supply can be run in tracking mode or adjustable output mode and includes short-to-ground and short-to-battery protection. Therefore, this regulator can power a sensor outside the module or electronic control unit (ECU).

The integrated charge pump provides overdrive voltage for the internal regulators. The charge pump can also be used in a reverse-battery protection circuit by using the charge-pump output to control an external NMOS transistor. This solution allows for a lower minimum-battery-voltage operation compared to a traditional reverse-battery blocking diode when the device must be operational at the lowest possible supply voltages.

The device monitors undervoltage and overvoltage on all regulator outputs, battery voltage, and internal supply rails. A second bandgap reference, independent from the main bandgap reference, is used for the undervoltage and overvoltage monitoring, to avoid any drifts in the main bandgap reference from being undetected. In addition, regulator current-limits and temperature protections are implemented.

The TPS65381A-Q1 device has monitoring and protection functions, which include the following: watchdog with trigger and *question and answer* modes, MCU error-signal monitor, clock monitoring on internal oscillators, self-check on the clock monitor, cyclic redundancy check (CRC) on nonvolatile memory, a diagnostic output pin allowing the MCU to observe internal analog and digital signals of the device, a reset circuit and output pin for the MCU, and an enable drive output to disable the safing-path or external-power stages on detected faults. A built-in self-test (BIST) monitors the device functionality automatically at power-up. A dedicated DIAGNOSTIC state allows the MCU to check TPS65381A-Q1 monitoring and protection functions.

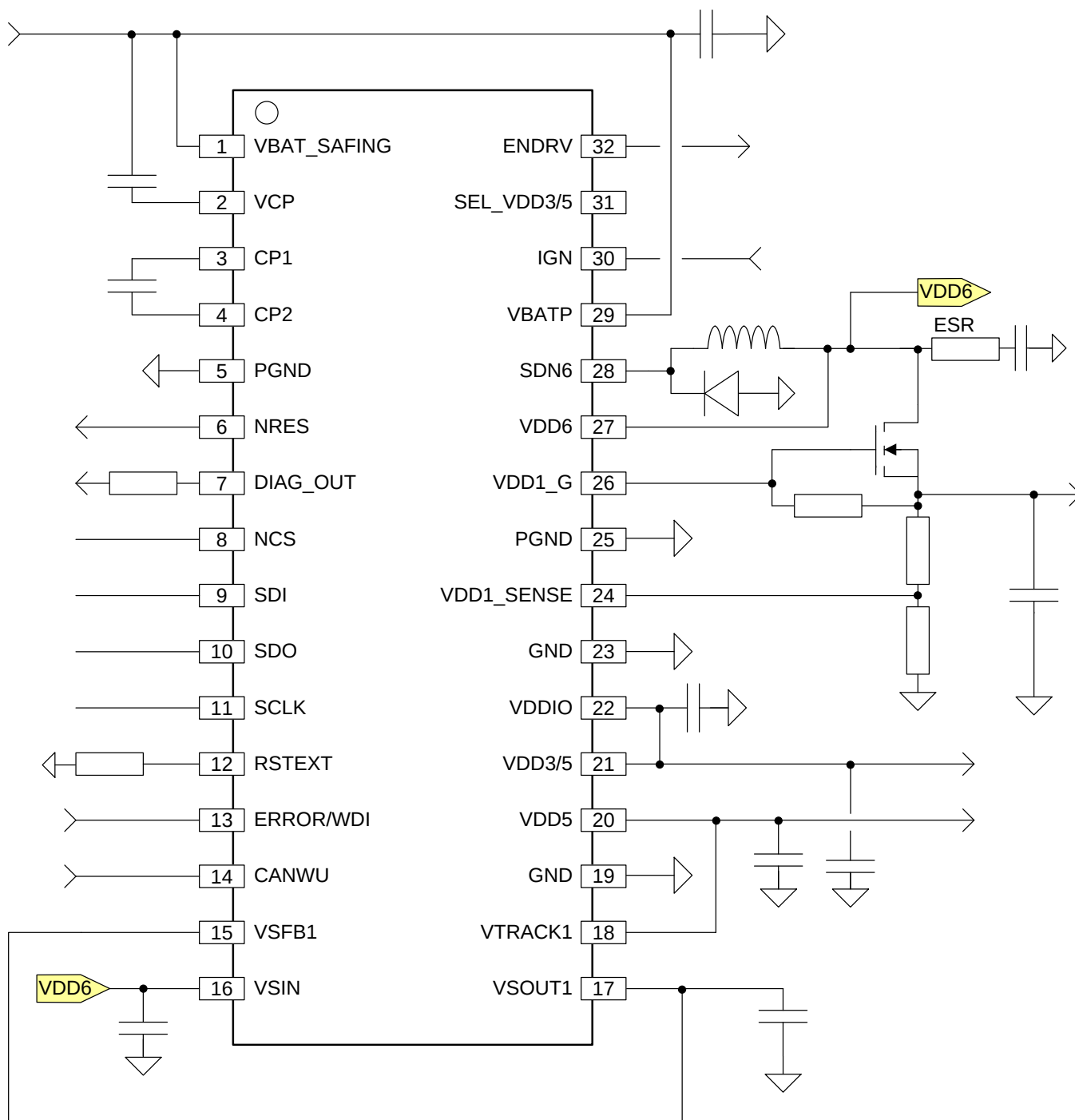
The TPS65381A-Q1 device is offered in a 32-pin HTSSOP PowerPAD package.

**Device Information<sup>(1)</sup>**

| PART NUMBER  | PACKAGE     | BODY SIZE (NOM)    |
|--------------|-------------|--------------------|
| TPS65381A-Q1 | HTSSOP (32) | 11.00 mm × 6.20 mm |

(1) For all available packages, see the orderable addendum at the end of the data sheet.

**1.4 Typical Application Diagram**



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**Figure 1-1. Typical Application Diagram**

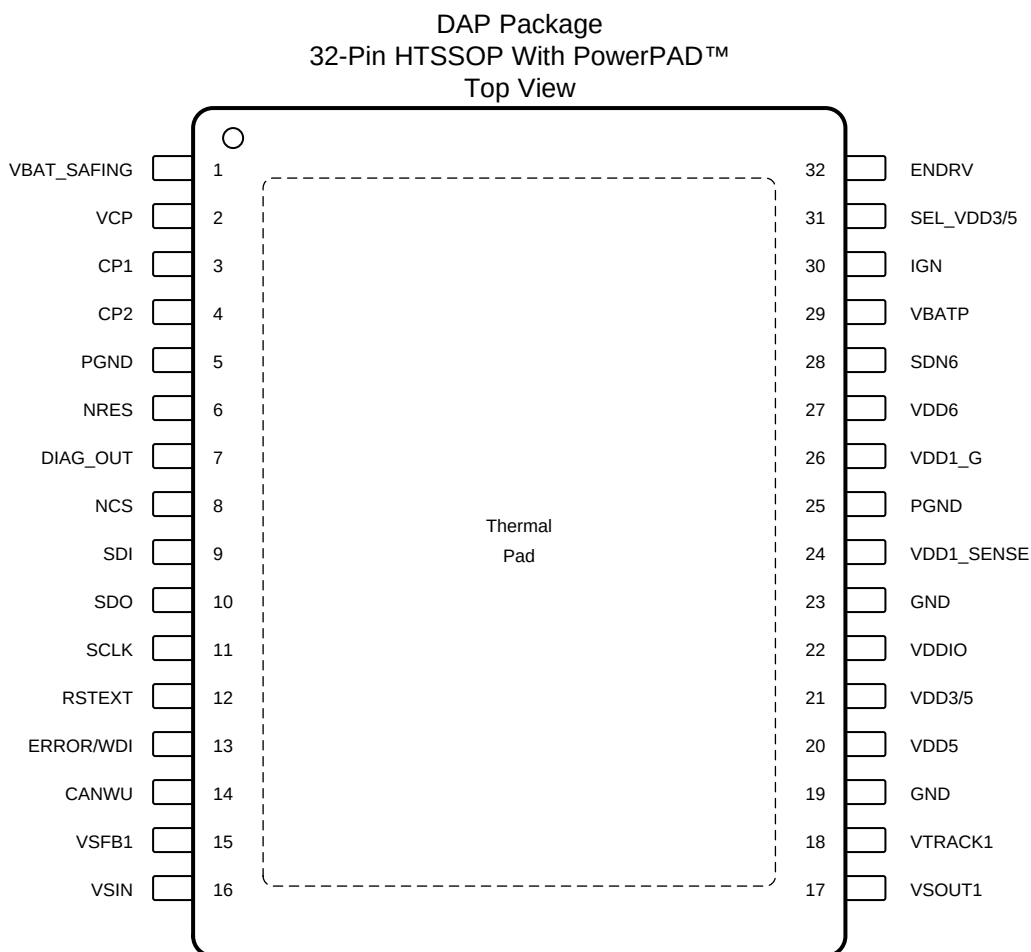
## 2 Revision History

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

| Changes from Original (July 2016) to Revision A                                                   | Page              |
|---------------------------------------------------------------------------------------------------|-------------------|
| <ul style="list-style-type: none"><li>Released the full version of the data sheet .....</li></ul> | <a href="#">2</a> |

### 3 Pin Configuration and Functions

The pin configuration drawing in this section is not to scale. For package dimensions, see the mechanical data in [Section 10](#).



#### Pin Functions

| PIN |             | TYPE | DESCRIPTION                                                                                                                     |
|-----|-------------|------|---------------------------------------------------------------------------------------------------------------------------------|
| NO. | NAME        |      |                                                                                                                                 |
| 1   | VBAT_SAFING | PWR  | Battery (supply) input for monitoring (VMON) and BG2 functions (must be reverse protected), should be connected to VBATP        |
| 2   | VCP         | PWR  | Charge-pump output voltage                                                                                                      |
| 3   | CP1         | PWR  | Charge-pump external capacitor, high-voltage side                                                                               |
| 4   | CP2         | PWR  | Charge-pump external capacitor, low-voltage side                                                                                |
| 5   | PGND        | GND  | Ground (power)                                                                                                                  |
| 6   | NRES        | O    | Cold reset output signal for the microcontroller (MCU) (active-low, internal pullup, open drain output)                         |
| 7   | DIAG_OUT    | O    | Diagnostic output pin for diagnostic MUX. Internal analog (AMUX) and digital (DMUX) signal connection to MCU ADC and digital IO |
| 8   | NCS         | I    | SPI chip select (active-low, internal pullup)                                                                                   |
| 9   | SDI         | I    | SPI serial data IN (internal pulldown)                                                                                          |
| 10  | SDO         | O    | SPI serial data OUT                                                                                                             |
| 11  | SCLK        | I    | SPI clock (internal pull down)                                                                                                  |
| 12  | RSTEXT      | I    | Configuration pin to set reset extension time through a resistor to GND                                                         |

## Pin Functions (continued)

| PIN |             | TYPE | DESCRIPTION                                                                                                                                                                             |
|-----|-------------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NO. | NAME        |      |                                                                                                                                                                                         |
| 13  | ERROR/WDI   | I    | Error input signal from the MCU while using the MCU ESM (with the watchdog in Q&A Mode), trigger input for the watchdog in trigger mode (MCU ESM not used). This pin is edge triggered. |
| 14  | CANWU       | I    | Wake-up input from CAN transceiver, other transceiver or other source. Wake-up request latched with CANWU_L. (internal pulldown)                                                        |
| 15  | VSFB1       | I    | Feedback input reference for sensor supply regulator (VSOUT1)                                                                                                                           |
| 16  | VSIN        | PWR  | Input supply voltage for the sensor-supply regulator (VSOUT1)                                                                                                                           |
| 17  | VSOUT1      | PWR  | Output voltage for the VSOUT1 sensor-supply regulator                                                                                                                                   |
| 18  | VTRACK1     | I    | Tracking input reference for sensor-supply regulator (VSOUT1) (internal pulldown)                                                                                                       |
| 19  | GND         | GND  | Ground (analog)                                                                                                                                                                         |
| 23  | GND         | GND  | Ground (analog)                                                                                                                                                                         |
| 20  | VDD5        | PWR  | VDD5 regulator output voltage                                                                                                                                                           |
| 21  | VDD3/5      | PWR  | VDD3/5 regulator output voltage                                                                                                                                                         |
| 22  | VDDIO       | PWR  | I/O supply input for pins to and from the MCU                                                                                                                                           |
| 24  | VDD1_SENSE  | I    | Reference input for VDD1 regulator (feedback) and input for UV/OV monitoring of VDD1 regulator                                                                                          |
| 25  | PGND        | GND  | Ground (power)                                                                                                                                                                          |
| 26  | VDD1_G      | O    | Gate drive of external FET for VDD1 regulator                                                                                                                                           |
| 27  | VDD6        | PWR  | VDD6 switch mode regulator feedback input and supply input for integrated VDD5 and VDD3/5 regulators                                                                                    |
| 28  | SDN6        | PWR  | Switching node for VDD6 switch mode regulator                                                                                                                                           |
| 29  | VBATP       | PWR  | Battery (supply) voltage (must be reverse protected), main power supply input for device                                                                                                |
| 30  | IGN         | I    | Wake-up input from ignition (key) or other source (internal pulldown)                                                                                                                   |
| 31  | SEL_VDD3/5  | I    | Input selects voltage level for VDD3/5 regulator (SEL_VDD3/5 pin open: 3.3-V regulation from VDD3/5; SEL_VDD3/5 pin to GND: 5-V regulation from VDD3/5)                                 |
| 32  | ENDRV       | O    | Enable output signal for peripherals (for example, motor-driver IC), safing path output (internal pullup, open drain output)                                                            |
| —   | Thermal pad | —    | Place thermal vias to large ground plane and connect to GND and PGND pins.                                                                                                              |

## 4 Specifications

### 4.1 Absolute Maximum Ratings

Over operating free-air temperature range (unless otherwise noted)<sup>(1)(2)</sup>

| POS   |                                                        |                                                            | MIN  | MAX                                 | UNIT |
|-------|--------------------------------------------------------|------------------------------------------------------------|------|-------------------------------------|------|
| M1.1  | Protected-battery voltage                              | VBATP, VBAT_SAFING, VSIN                                   | −0.3 | 40                                  | V    |
| M1.2  | Charge-pump voltage                                    | VCP, CP1 <sup>(3)</sup>                                    | −0.3 | lesser of<br>VBATP<br>+ 16 or<br>52 | V    |
| M1.3  | Charge-pump pumping capacitor voltage                  | CP2                                                        | −0.3 | 40                                  | V    |
| M1.3a | Charge-pump overdrive voltage                          | VCP <sup>(3)</sup> -VBATP                                  | −0.3 | 16                                  | V    |
| M1.4  | VDD6 switching-node voltage                            | SDN6                                                       | −0.3 | 40                                  | V    |
| M1.5  | VDD6 output voltage                                    | VDD6                                                       | −0.3 | 40                                  | V    |
| M1.6  | VDD5 output voltage                                    | VDD5                                                       | −0.3 | 7                                   | V    |
| M1.7  | VDD3/5 output voltage                                  | VDD3/5                                                     | −0.3 | 7                                   | V    |
| M1.8  | VDD1_G voltage                                         | VDD1_G                                                     | −0.3 | 15                                  | V    |
| M1.10 | VDD1_SENSE voltage                                     | VDD1_SENSE                                                 | −0.3 | 7                                   | V    |
| M1.11 | Sensor supply tracking voltage                         | VTRACK1                                                    | −0.3 | 40                                  | V    |
| M1.12 | Sensor supply output and feedback voltage              | VSOUT1, VSFB1 <sup>(4)</sup>                               | −2   | 18                                  | V    |
| M1.14 | Analog/digital reference output voltage                | DIAG_OUT                                                   | −0.3 | 7                                   | V    |
| M1.15 | Logic I/O voltage                                      | VDDIO, ERROR/WDI, ENDRV, NRES, NCS, SDI, SDO, SCLK, RSTEXT | −0.3 | 7                                   | V    |
| M1.16 |                                                        | SEL_VDD3/5                                                 | −0.3 | 40                                  | V    |
| M1.17 | IGN wakeup                                             | IGN                                                        | −7   | 40                                  | V    |
| M1.18 | CAN wakeup                                             | CANWU                                                      | −0.3 | 40                                  | V    |
| M1.19 | Operating virtual junction temperature, T <sub>j</sub> |                                                            |      | 150                                 | °C   |
|       | Storage temperature, T <sub>stg</sub>                  |                                                            | −65  | 150                                 | °C   |

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) All voltage values are with respect to the network ground pin unless otherwise noted.
- (3) VCP and CP1 are output pins, no external voltage should be applied to these pins. Absolute Maximum ratings for these pins are what may appear on the pins.
- (4) VSOUT1 is connected to VSFB1 directly (for unity gain) or through resistor divider (tracking mode gain or non-tracking mode output voltage adjusting). In case of a short to supply fault, the voltage on VSOUT1 is equal to the supply to the device (VBATP, VBAT\_SAFING, and VSIN where VSIN is connected to VBATP as it's supply instead of VDD6) and VSFB1 voltage will follow VSOUT1 based on the use case, directly (for unity gain) or via resistor divider (tracking mode gain or non-tracking mode output voltage adjusting).

### 4.2 ESD Ratings

| POS.  |                    |                                                         | VALUE                                            | UNIT  |
|-------|--------------------|---------------------------------------------------------|--------------------------------------------------|-------|
| M1.21 | V <sub>(ESD)</sub> | Human body model (HBM), per AEC Q100-002 <sup>(1)</sup> | All pins except VSOUT1 (17) and VSFB1 (15)       | ±2000 |
| M1.20 |                    |                                                         | On sensor supply pins VSOUT1 (17) and VSFB1 (15) | ±4000 |
| M1.22 |                    | Charged device model (CDM), per AEC Q100-011            | Corner pins (1, 16, 17, and 32)                  | ±750  |
| M1.23 |                    |                                                         | All pins                                         | ±500  |

- (1) AEC Q100-002 indicates that HBM stressing is done in accordance with the ANSI/ESDA/JEDEC JS-001 Specification.

### 4.3 Recommended Operating Conditions

Over operating temperature range and with respect to the GND and PGND (GND = PGND) pins (unless otherwise noted)

| POS    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | MIN | MAX                | UNIT |
|--------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|--------------------|------|
| M1.20a | Operating ambient temperature, $T_A$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | -40 | 125                | °C   |
| R1.1   | Minimum input supply voltage on VBATP for initial power up (POS 6.2, VBATP_UV <sub>on</sub> ) <sup>(1)(2)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |     | 5.8 <sup>(3)</sup> | V    |
| R1.2   | Input supply voltage on VBATP <sup>(1)(2)(4)</sup> <ul style="list-style-type: none"> <li>To support operation when VBATP is between 5.8 V and 7 V, the device remains functional. Some rails can be in dropout or undervoltage depending on actual input supply and the configuration of the specific regulator.</li> <li>VDD6 can be in dropout mode (100% duty cycle)</li> <li>VDD3/5 configured for 5-V output can be in dropout. If the output reaches VDD3/5_UV threshold, the device transitions to the RESET state because of a VDD3/5 undervoltage event. If VDD3/5 is configured for 3.3-V output it remains functional.</li> <li>VDD5 can be in dropout. If output reaches the VDD5_UV threshold, the device indicates the undervoltage event through the VDD5_UV status bit.</li> <li>VSOUT1 can be in dropout depending on configuration. If output reaches VSOUT1_UV threshold, the device indicates the undervoltage event through the VSOUT1_UV status bit.</li> </ul>                                                         | 5.8 | 34 <sup>(5)</sup>  | V    |
| R1.3   | Input supply voltage on VBATP after initial power up, functional operation during low input supply voltage events, (POS 6.1, VBATP_UV <sub>off</sub> ) <sup>(1)(6)</sup> <ul style="list-style-type: none"> <li>The device remains functional. Some rails can be in dropout or undervoltage depending on actual input supply and the configuration of the specific regulator.</li> <li>VDD6 is in dropout mode (100% duty cycle).</li> <li>VDD3/5 configured for 5-V output can be in dropout. If the output reaches VDD3/5_UV threshold, the device transitions to the RESET state because of a VDD3/5 undervoltage event. If VDD3/5 is configured for 3.3-V output it remains functional.</li> <li>VDD5 can be in dropout. If the output reaches VDD5_UV threshold, the device indicates the undervoltage event through the VDD5_UV status bit.</li> <li>VSOUT1 may be in dropout depending on configuration, if output reaches VSOUT1_UV threshold the device indicates the undervoltage event through the VSOUT1_UV status bit.</li> </ul> | 4.5 | 5.8                | V    |
| R1.4   | VDDIO supply-voltage range                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 3.3 | 5                  | V    |
| R1.5   | Current consumption in standby mode (all regulator outputs disabled)<br>IGN = 0 V, CANWU = 0 V, 5.8 V ≤ VBAT ≤ 20 V for $T_J < 85^\circ\text{C}$ or 5.8 V ≤ VBAT ≤ 14 V for $T_J = 125^\circ\text{C}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |     | 75                 | μA   |

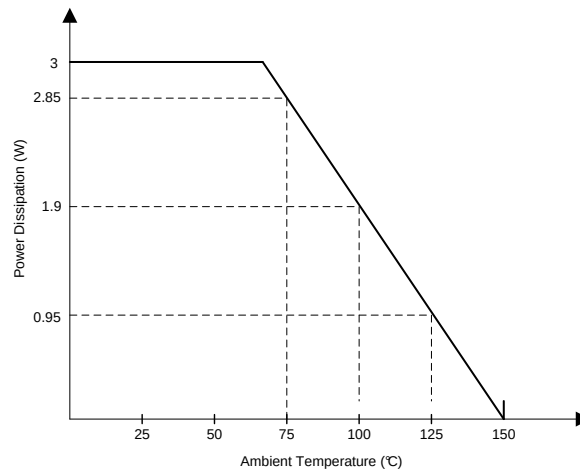
- (1) VBATP should be connected to VBAT\_SAFING.
- (2) VBAT\_SAFING has a supply high enough to power the VMON block and internal rail AVDD\_VMON above AVDD\_VMON\_UV.
- (3) The device may power up when VBATP is less than 5.8 V, but it will always power up when VBATP is 5.8V or greater, while VBAT\_SAFING has a supply high enough to power the VMON block and internal rail AVDD\_VMON above AVDD\_VMON\_UV.
- (4) Under slow VBAT ramp-down and when VDD3/5 rail is configured as a 5-V rail, the NRES output can be pulled low when VBAT is at approximately 6.3 V. This occurs because of an undervoltage transient on the VDD3/5 rail.  
Under slow VBAT ramp-up and when VDD3/5 rail is configured as a 5-V rail, the NRES output can be pulled low when VBAT is at approximately 6.6 V. This occurs because of an undervoltage transient on VDD3/5 rail. Under similar conditions, undervoltage transients are observed on VDD5 and VSOUT1 rails (refer to [Device Behavior Under Slow VBAT Ramp-Up and Ramp-Down](#)).
- (5) The recommended maximum operating voltage for VBATP and VBAT\_SAFING is listed as 34 V, just below the overvoltage detection thresholds for VBATP, VBATP\_OV<sub>rise</sub> and VBATP\_OV<sub>fall</sub>. TI recommends enabling overvoltage detection on VBATP (default is enabled, MASK\_VBATP\_OV = 0). TI also recommends evaluating the thermal and power dissipation of the device in the application and ensure the design has adequate thermal management for operation at the necessary supply voltage level.
- (6) The device will remain on if VBATP drops from 5.8V down to VBATP\_UV<sub>off</sub> threshold or another voltage monitor detects an undervoltage on a specific rail and changes the device state. VBAT\_UV<sub>off</sub> can be detected at 4.5 V but could be detected as low as 4.2 V. VBAT\_SAFING has a supply high enough to power the VMON block and internal rail AVDD\_VMON above AVDD\_VMON\_UV.



## 4.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |                                              | TPS65381A-Q1 | UNIT |
|-------------------------------|----------------------------------------------|--------------|------|
|                               |                                              | DAP (HTSSOP) |      |
|                               |                                              | 32 PINS      |      |
| $R_{\theta JA}$               | Junction-to-ambient thermal resistance       | 26.3         | °C/W |
| $R_{\theta JC(top)}$          | Junction-to-case (top) thermal resistance    | 14.1         | °C/W |
| $R_{\theta JB}$               | Junction-to-board thermal resistance         | 6            | °C/W |
| $\Psi_{JT}$                   | Junction-to-top characterization parameter   | 0.2          | °C/W |
| $\Psi_{JB}$                   | Junction-to-board characterization parameter | 6.2          | °C/W |
| $R_{\theta JC(bot)}$          | Junction-to-case (bottom) thermal resistance | 0.5          | °C/W |

- (1) For more information about traditional and new thermal metrics, see the [Semiconductor and IC Package Thermal Metrics](#) application report.



- (1) In applications where high power dissipation and/or poor package thermal resistance is present, the maximum ambient temperature may have to be derated. Maximum ambient temperature ( $T_{Amax}$ ) is dependent on the maximum-operating junction temperature ( $T_{Jmax}$ ), the maximum power dissipation of the device in the application ( $P_{Dmax}$ ), and the junction-to-ambient thermal resistance of the part/package in the application ( $R_{\theta JA}$ ), as given by the following equation:  $T_{Amax} = T_{Jmax} - (R_{\theta JA} \times P_{Dmax})$ .
- (2) Maximum power dissipation is a function of  $T_{Jmax}$ ,  $R_{\theta JA}$ , and  $T_A$ . The maximum-allowable power dissipation at any allowable ambient temperature is  $P_D = (T_{Jmax} - T_A) / R_{\theta JA}$ .

**Figure 4-1. Derating Profile for Power Dissipation Based on High-K JEDEC PCB**

## 4.5 Electrical Characteristics

Over operating ambient temperature  $T_A = -40^{\circ}\text{C}$  to the maximum-operating junction temperature  $T_J = 150^{\circ}\text{C}$ , and with  $\text{VBATP} = \text{VBAT\_SAFING}$  in the recommended operating range (see R1.2 in [Section 4.3](#)) (unless otherwise noted)

| POS                          | PARAMETER               |                                                                                                                      | TEST CONDITIONS                                                                                                                                                                                                  | MIN               | TYP  | MAX  | UNIT |
|------------------------------|-------------------------|----------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|------|------|------|
| VDD6-BUCK WITH INTERNAL FET  |                         |                                                                                                                      |                                                                                                                                                                                                                  |                   |      |      |      |
| AN                           | C <sub>VDD6</sub>       | Value of output ceramic capacitor <sup>(1)</sup>                                                                     | ESR range 100 mΩ to 300 mΩ <sup>(2)</sup>                                                                                                                                                                        | 22                |      | 47   | μF   |
| AN                           | L <sub>VDD6</sub>       | Value of inductor                                                                                                    |                                                                                                                                                                                                                  | 22                | 33   |      | μH   |
| 1.1                          | VDD6                    | VDD6 output voltage                                                                                                  | Average DC value excluding ripple and load transients, VBAT > 7 V, 0 < I <sub>VDD6</sub> < 1.3 A, including dc line and load regulation, temperature drift, and long-term drift where VBAT = VBATP = VBAT_SAFING | 5.4               | 6    | 6.6  | V    |
| 1.1a                         | VDD6 <sub>ripple</sub>  | VDD6 ripple voltage                                                                                                  | Peak-to-peak, ensured by design<br>VBATP = VBAT_SAFING = 14 V, L = 33 μH, C = 22 μF                                                                                                                              |                   | 200  |      | mV   |
| 1.2                          | I <sub>VDD6</sub>       | VDD6 output current I <sub>VDD5</sub> + I <sub>VDD3/5</sub> + I <sub>VDD1</sub> + I <sub>VSOUT1</sub> <sup>(3)</sup> |                                                                                                                                                                                                                  |                   |      | 1.3  | A    |
| 1.3                          | V <sub>dropout6</sub>   | VDD6 output dropout voltage V <sub>dropout6</sub> = (VBATP – SDN6)                                                   | I <sub>VDD6</sub> = 1.3 A<br>(example: R <sub>DS(on)</sub> = 0.46 Ω)                                                                                                                                             |                   |      | 0.6  | V    |
| 1.4                          | I <sub>VDD6_limit</sub> | Peak current out of SDN6 pin <sup>(4)</sup>                                                                          |                                                                                                                                                                                                                  | 1.5               |      | 2.5  | A    |
| 1.5                          | f <sub>clk_VDD6</sub>   | Clock Frequency <sup>(5)</sup>                                                                                       |                                                                                                                                                                                                                  | 396               | 440  | 484  | kHz  |
| 1.6                          | DC <sub>VDD6</sub>      | t <sub>on</sub> /t <sub>period</sub>                                                                                 | 0 < I <sub>VDD6</sub> < 1.3 A<br>VDD6 enters dropout mode (100% duty cycle) for VBATP < 7 V                                                                                                                      | 7% <sup>(6)</sup> |      | 100% |      |
| 1.7                          | T <sub>protVDD6</sub>   | Temperature protection threshold <sup>(7)</sup>                                                                      |                                                                                                                                                                                                                  | 175               |      | 210  | °C   |
| VDD5 – LDO WITH INTERNAL FET |                         |                                                                                                                      |                                                                                                                                                                                                                  |                   |      |      |      |
| AN                           | C <sub>VDD5</sub>       | Value of output ceramic capacitor                                                                                    | ESR range 0 mΩ to 100 mΩ                                                                                                                                                                                         | 1                 |      | 5    | μF   |
| 2.1                          | VDD5                    | VDD5 output voltage <sup>(8)</sup>                                                                                   | 0 < I <sub>VDD5</sub> < 300 mA                                                                                                                                                                                   | 4.9               | 5    | 5.1  | V    |
| 2.2                          | I <sub>VDD5</sub>       | VDD5 output current, including load from the internal resistor of 660 Ω (typical)                                    |                                                                                                                                                                                                                  |                   |      | 300  | mA   |
| 2.3                          | VDD5 <sub>dyn</sub>     | VDD5 output voltage dynamic                                                                                          | Load step 20% to 80% in 5 μs, with C <sub>VDD5</sub> = 5 μF                                                                                                                                                      | 4.85              | 5    | 5.15 | V    |
| 2.4                          | VDD5 <sub>max</sub>     | Maximum VDD5 output voltage during VBATP step from 5.5 V to 13.5 V within 10 μs                                      | C <sub>VDD5</sub> = 5 μF, I <sub>VDD5</sub> < 300 mA                                                                                                                                                             |                   |      | 5.5  | V    |
| 2.5                          | V <sub>dropout5</sub>   | VDD5 output dropout voltage V <sub>dropout5</sub> = (VDD6 – VDD5)                                                    | I <sub>VDD5</sub> < 300 mA                                                                                                                                                                                       |                   |      | 0.3  | V    |
| 2.6                          | PSRR <sub>VDD5</sub>    | Power supply rejection ratio                                                                                         | 50 < f < 20 kHz, VBATP = 10 V, U = 4 Vpp, C <sub>VDD5</sub> = 5 μF, 0 < I <sub>VDD5</sub> < 300 mA                                                                                                               |                   | > 40 |      | dB   |
| 2.7                          | LnReg <sub>VDD5</sub>   | Line regulation (I <sub>VDD5</sub> constant)                                                                         | 0 < I <sub>VDD5</sub> < 300 mA,<br>8 V < VBATP < 19 V                                                                                                                                                            | –25               |      | 25   | mV   |
| 2.8                          | LdReg <sub>VDD5</sub>   | Load regulation (VDD6 constant)                                                                                      | 0 < I <sub>VDD5</sub> < 300 mA,<br>8 V < VBATP < 19 V                                                                                                                                                            | –25               |      | 25   | mV   |
| 2.9                          | TmpCo <sub>VDD5</sub>   | Temperature drift                                                                                                    | Normalized to 25°C value                                                                                                                                                                                         | –0.5%             |      | 0.5% |      |
| 2.11                         | dVDD5/dt                | dV/dt at VDD5 at startup                                                                                             | Between 10% and 90% of VDD5 end-value                                                                                                                                                                            | 5                 |      | 50   | V/ms |
| 2.13                         | T <sub>protVDD5</sub>   | Temperature protection threshold <sup>(9)</sup>                                                                      |                                                                                                                                                                                                                  | 175               |      | 210  | °C   |
| 2.14                         | I <sub>VDD5_limit</sub> | Current-limit <sup>(10)</sup>                                                                                        |                                                                                                                                                                                                                  | 350               |      | 650  | mA   |

- (1) Capacitance is effective capacitance after derating for operating voltage, temperature, and lifetime.
- (2) ESR is total effective series resistance of the capacitors and if necessary added series resistor.
- (3)  $I_{\text{VDD6}}$  is the load current from VDD5, VDD3/5, VDD1 and VSOUT1 on VDD6 regulator; VDD6 is not recommended to be loaded directly for applications or peripherals that cannot operate with wider tolerance and ripple since VDD6 is a pre-regulator. However, LDOs or DC-DC converters may be connected directly as long as the total load current on VDD6,  $I_{\text{VDD6}}$ , does not exceed the specification for VDD6 load current.
- (4) VDD6 current limit is based on the peak current through SDN6 switch, it will not directly correspond to an average current limit.
- (5) Actual switching on SDN6 depends on whether output voltage on VDD6 is above or below hysteretic PWM comparator threshold at the moment of the rising edge of the  $F_{\text{clk\_VDD6}}$  clock. If no switching is needed when the rising edge of the  $F_{\text{clk\_VDD6}}$  clock occurs, SDN6 will not switch on. SDN6 turn off is determined by the hysteretic PWM comparator threshold, when the actual VDD6 voltage is above the threshold SDN6 will turn off.
- (6) When the VDD6 control loop turns the SDN6 switch on at the rising edge of a  $f_{\text{clk\_VDD6}}$  clock cycle, SDN6 will remain on with a minimum duty cycle of 7%. However, if the control loop skips a clock cycle the duty cycle will be 0% for that  $f_{\text{clk\_VDD6}}$  clock cycle.
- (7) Protection of VDD6, shared with VDD3/5 overtemperature protection.
- (8) VDD5 output regulation includes line and load regulation, temperature drift.
- (9) Protection of VDD5. In case of detected overtemperature, only VDD5 will be switched off.
- (10)  $I_{\text{VDD5\_limit}}$  current limit has snap back behavior. During a short circuit condition, a transient current higher than the maximum will occur until the current limit snaps back into the specified range.

## Electrical Characteristics (continued)

Over operating ambient temperature  $T_A = -40^{\circ}\text{C}$  to the maximum-operating junction temperature  $T_J = 150^{\circ}\text{C}$ , and with  $\text{VBATP} = \text{VBAT\_SAFING}$  in the recommended operating range (see R1.2 in [Section 4.3](#)) (unless otherwise noted)

| POS                                      | PARAMETER                  |                                                                                                                                                    | TEST CONDITIONS                                                                                            |                      | MIN   | TYP | MAX   | UNIT |
|------------------------------------------|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|----------------------|-------|-----|-------|------|
| VDD3/5 – LDO WITH INTERNAL FET           |                            |                                                                                                                                                    |                                                                                                            |                      |       |     |       |      |
| AN                                       | C <sub>VDD3/5</sub>        | Value of output ceramic capacitor                                                                                                                  | ESR range 0 mΩ to 100 mΩ                                                                                   |                      | 1     |     | 5     | μF   |
| 3.1a                                     | VDD3/5                     | VDD3/5 output voltage, SEL_VDD3/5 pin: open = 3.3 V setting, ground = 5 V setting                                                                  | 0 < I <sub>VDD3/5</sub> < 300 mA                                                                           | 3.3-V Setting        | 3.234 | 3.3 | 3.366 | V    |
| 3.1b                                     |                            |                                                                                                                                                    |                                                                                                            | 5-V Setting          | 4.9   | 5   | 5.1   |      |
| 3.2                                      | I <sub>VDD3/5</sub>        | VDD3/5 output current, including load from the internal resistor of 440 Ω (typ.) for 3.3 V setting or 660 Ω (typ.) for 5 V setting <sup>(11)</sup> |                                                                                                            |                      |       |     | 300   | mA   |
| 3.3a                                     | VDD3/5 <sub>dyn</sub>      | VDD3/5 output voltage dynamic                                                                                                                      | Load step 20% to 80% in 5 μs, with C <sub>VDD3/5</sub> = 5 μF                                              | 3.3-V Setting        | 3.15  | 3.3 | 3.43  | V    |
| 3.3b                                     |                            |                                                                                                                                                    |                                                                                                            | 5-V Setting          | 4.85  | 5   | 5.15  |      |
| 3.4                                      | VDD3/5 <sub>max</sub>      | Maximum VDD3/5 output voltage during VBATP step from 5.5 V to 13.5 V within 10 μs                                                                  | C <sub>VDD3/5</sub> = 5 μF, I <sub>VDD3/5</sub> < 300 mA                                                   | 3.3-V Setting        |       |     | 3.6   | V    |
|                                          |                            |                                                                                                                                                    |                                                                                                            | 5-V Setting          |       |     | 5.5   |      |
| 3.5                                      | Vdropout3/5                | VDD3/5 output dropout voltage Vdropout3/5 = (VDD6–VDD3/5)                                                                                          | I <sub>VDD3/5</sub> < 300 mA                                                                               |                      |       |     | 0.3   | V    |
| 3.6                                      | PSRR <sub>VDD3/5</sub>     | Power-supply rejection ratio                                                                                                                       | 50 < f < 20 kHz, VBATP = 10 V, U = 4 Vpp<br>C <sub>VDD3/5</sub> = 5 μF, 0 < I <sub>VDD3/5</sub> < 300 mA   |                      | > 40  |     |       | dB   |
| 3.7                                      | LnReg <sub>VDD3/5</sub>    | Line regulation (I <sub>VDD3</sub> constant)                                                                                                       | 0 < I <sub>VDD3/5</sub> < 300 mA,<br>8 V < VBATP < 19 V                                                    |                      | –25   |     | 25    | mV   |
| 3.8                                      | LdReg <sub>VDD3/5</sub>    | Load regulation (VDD6 constant)                                                                                                                    | 0 < I <sub>VDD3/5</sub> < 300 mA<br>8 V < VBATP < 19 V                                                     |                      | –25   |     | 25    | mV   |
| 3.9                                      | TmpCo <sub>VDD3/5</sub>    | Temperature drift                                                                                                                                  | Normalized to 25°C value                                                                                   |                      | –0.5% |     | 0.5%  |      |
| 3.11                                     | dVDD35/dt                  | dV/dt at VDD3/5 at start-up                                                                                                                        | Between 10% and 90% of VDD3/5 end-value                                                                    | 3.3-V Setting        | 3     |     | 30    | V/ms |
|                                          |                            |                                                                                                                                                    |                                                                                                            | 5-V Setting          | 5     |     | 50    |      |
| 3.13                                     | Tprot <sub>VDD3/5</sub>    | Temperature protection threshold <sup>(12)</sup>                                                                                                   |                                                                                                            |                      | 175   |     | 210   | °C   |
| 3.14                                     | I <sub>VDD3/5_limit</sub>  | Current-limit <sup>(13)</sup>                                                                                                                      |                                                                                                            |                      | 350   |     | 650   | mA   |
| 3.15                                     | I <sub>pu_SEL_VDD3/5</sub> | Pullup current on SEL_VDD3/5 pin                                                                                                                   |                                                                                                            |                      |       |     | 20    | μA   |
| VDD1 – LDO WITH EXTERNAL FET             |                            |                                                                                                                                                    |                                                                                                            |                      |       |     |       |      |
| AN                                       | Vgs(th)                    | Gate threshold voltage, external FET                                                                                                               | ID = 1 mA                                                                                                  |                      | 0.3   |     | 3     | V    |
| AN                                       | Ciss                       | Gate capacitance, external FET                                                                                                                     | VGS = 0 V                                                                                                  |                      |       |     | 3200  | pF   |
| AN                                       | Qgate                      | Gate Charge, external FET                                                                                                                          | VGS = 0 V to 10 V                                                                                          |                      |       |     | 70    | nC   |
| AN                                       | gfs                        | Forward transconductance, external FET                                                                                                             | ID = 50 mA                                                                                                 |                      | 0.4   |     |       | S    |
| AN                                       | C <sub>VDD1</sub>          | Value of output ceramic capacitor                                                                                                                  | ESR range 0 mΩ to 100 mΩ                                                                                   |                      | 5     |     | 40    | μF   |
| 4.1                                      | VDD1                       | VDD1 output voltage, depends on external resistive divider                                                                                         |                                                                                                            |                      | 0.8   |     | 3.3   | V    |
| 4.2                                      | VDD1 <sub>SENSE</sub>      | VDD1 reference voltage <sup>(14)</sup>                                                                                                             | 10 mA < I <sub>VDD1</sub> < 600 mA                                                                         |                      | 0.792 | 0.8 | 0.808 | V    |
| 4.2a                                     | VDD1 <sub>SENSE_BIAS</sub> | Bias current of VDD1 <sub>SENSE</sub>                                                                                                              |                                                                                                            |                      | –6.6  |     | –10   | μA   |
| 4.3                                      | I <sub>VDD1</sub>          | VDD1 output current                                                                                                                                | Minimum current realized with external resistive divider                                                   |                      | 10    |     | 600   | mA   |
| 4.4                                      | VDD1 <sub>G</sub>          | VDD1 <sub>G</sub> output voltage                                                                                                                   | Referenced to GND                                                                                          |                      |       |     | 15    | V    |
| 4.5                                      | VDD1 <sub>G_off</sub>      | VDD1 <sub>G</sub> voltage in OFF condition                                                                                                         | 20 μA into VDD1 <sub>G</sub> pin                                                                           |                      |       |     | 0.3   | V    |
| 4.6                                      | I <sub>VDD1G</sub>         | VDD1 <sub>G</sub> DC load current                                                                                                                  |                                                                                                            |                      |       |     | 200   | μA   |
| 4.7                                      | VDD1 <sub>dyn</sub>        | VDD1 output voltage dynamic                                                                                                                        | Load step 10% to 90% in 1 μs, with CVDD1 = 40 μF <sup>(15)</sup>                                           |                      | ± 4%  |     |       |      |
| 4.8                                      | VDD1 <sub>max</sub>        | Maximum VDD1 output voltage during VBATP step from 5.5 V to 13.5 V within 10 μs                                                                    | C <sub>VDD1</sub> > 6 μF, I <sub>VDD1</sub> < 600 mA                                                       | VDD1 = 0.8-V output  |       |     | 0.898 | V    |
|                                          |                            |                                                                                                                                                    |                                                                                                            | VDD1 = 1.23-V output |       |     | 1.287 |      |
|                                          |                            |                                                                                                                                                    |                                                                                                            | VDD1 = 3.3-V output  |       |     | 3.435 |      |
| 4.9                                      | PSRR <sub>VDD1</sub>       | Power-supply rejection ratio                                                                                                                       | 50 < f < 20 kHz, VBATP = 10 V, U = 4 Vpp,<br>C <sub>VDD1</sub> = 10 μF, 10 mA < I <sub>VDD1</sub> < 600 mA |                      | > 40  |     |       | dB   |
| 4.10                                     | LnReg <sub>VDD1</sub>      | Line regulation on VDD1_SENSE (I <sub>VDD1</sub> constant)                                                                                         | 10 mA < I <sub>VDD1</sub> < 600 mA, 8 V < VBATP < 19 V                                                     |                      | –7    |     | 7     | mV   |
| 4.11                                     | LdReg <sub>VDD1</sub>      | Load regulation on VDD1_SENSE (VDD6 constant)                                                                                                      | 10 mA < I <sub>VDD1</sub> < 600 mA, 8 V < VBATP < 19 V                                                     |                      | –7    |     | 7     | mV   |
| 4.12                                     | TmpCo <sub>VDD1</sub>      | Temperature drift                                                                                                                                  | Normalized to 25°C value                                                                                   |                      | –0.5% |     | 0.5%  |      |
| 4.14                                     | dVDD1/dt                   | dV/dt at VDD1_SENSE at start-up                                                                                                                    | Between 10% and 90% of VDD1 end-value                                                                      |                      | 0.8   |     | 8     | V/ms |
| VSOUT1 – LDO WITH PROTECTED INTERNAL FET |                            |                                                                                                                                                    |                                                                                                            |                      |       |     |       |      |

(11) Less than 50% of maximum loading of  $I_{\text{VDD3/5}}$  should be placed on the VDD3/5 regulator before NRES goes high during device power up.

(12) Protection of VDD3/5, treated as global overtemperature (shutdown for all regulators).

(13)  $I_{\text{VDD3/5\_limit}}$  current limit has snap back behavior. During a short circuit condition, a transient current higher than the maximum will occur until the current limit snaps back into the specified range.

(14) VDD1 regulation including line and load regulation, temperature drift and long-term drift. Does not include tolerance of resistor divider to set VDD1 output voltage.

(15) VDD1<sub>dyn</sub> will depend on external FET choice

## Electrical Characteristics *(continued)*

Over operating ambient temperature  $T_A = -40^{\circ}\text{C}$  to the maximum-operating junction temperature  $T_J = 150^{\circ}\text{C}$ , and with  $\text{VBATP} = \text{VBAT\_SAFING}$  in the recommended operating range (see R1.2 in [Section 4.3](#)) (unless otherwise noted)

| POS                | PARAMETER                             |                                                                                                                                                                       | TEST CONDITIONS                                                                                                                             |               | MIN   | TYP  | MAX  | UNIT |
|--------------------|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|---------------|-------|------|------|------|
| AN                 | C <sub>VSOUT1</sub>                   | Value of output ceramic capacitor                                                                                                                                     | ESR range 0 mΩ to 100 mΩ                                                                                                                    |               | 0.5   |      | 10   | μF   |
| 5.1                | VSOUT1                                | VSOUT1 output voltage, depends on external resistive divider and tracking or non-tracking mode                                                                        |                                                                                                                                             |               | 3.3   |      | 9.5  | V    |
| 5.2                | MV <sub>VSOUT1</sub>                  | For tracking mode:<br>Matching output error MV <sub>VSOUT1</sub> = (VTRACK1 – VSFB1) <sup>(16)</sup>                                                                  | 0 < I <sub>VSOUT1</sub> < 100 mA                                                                                                            |               | –35   |      | 35   | mV   |
| 5.3                | VSFB1                                 | For non-tracking mode: VSOUT1 reference voltage <sup>(17)</sup>                                                                                                       | 10 mA < I <sub>VSOUT1</sub> < 100 mA                                                                                                        |               | 2.45  | 2.5  | 2.55 | V    |
| 5.3a               | VTRACK1 <sub>th</sub>                 | Threshold for selecting tracking/non-tracking mode (VTRACK1 > VTRACK1 <sub>th_max</sub> V for tracking mode, VTRACK1 < VTRACK1 <sub>th_min</sub> V non-tracking mode) |                                                                                                                                             |               | 1.1   | 1.2  | 1.3  | V    |
| 5.3b               | VTRACK1 <sub>pd</sub>                 | Internal pulldown resistance on VTRACK1 pin                                                                                                                           |                                                                                                                                             |               | 100   |      |      | kΩ   |
| 5.4                | I <sub>VSOUT1</sub>                   | VSOUT1 output current, including internal resistor to dissipate minimum current <sup>(18)</sup>                                                                       |                                                                                                                                             |               | 100   |      |      | mA   |
| 5.5                | VdrS1                                 | VSOUT1 dropout voltage VdrS1 = (VSIN-VSOUT1)                                                                                                                          | 0 < I <sub>VSOUT1</sub> < 100 mA                                                                                                            |               | 0.75  |      |      | V    |
| 5.6                | PSRR <sub>VSOUT1</sub>                | Power-supply rejection ratio                                                                                                                                          | With VTRACK1 = GND, VSOUT1 = 4.5V, 50 < f < 20 kHz, VSIN = 10 V, U = 4 Vpp<br>C <sub>VSOUT1</sub> = 1 μF, 0 < I <sub>VSOUT1</sub> < 100 mA, |               | > 40  |      |      | dB   |
| 5.7                | LnReg <sub>VSOUT1</sub>               | Line regulation (I <sub>VSOUT1</sub> constant)                                                                                                                        | 0 < I <sub>VSOUT1</sub> < 100 mA, 8 V < VSIN < 19 V                                                                                         |               | –25   |      | 25   | mV   |
| 5.8                | LdReg <sub>VSOUT1</sub>               | Load regulation (VSIN constant)                                                                                                                                       | 0 < I <sub>VSOUT1</sub> < 100 mA, 8 V < VSIN < 19 V                                                                                         |               | –35   |      | 35   | mV   |
| 5.9                | TmpC <sub>oVSOUT1</sub>               | Temperature drift                                                                                                                                                     | Normalized to 25°C value                                                                                                                    |               | –0.5% |      | 0.5% |      |
| 5.11               | VSOUT1 <sub>SH</sub>                  | Output short circuit voltage range                                                                                                                                    | VSOUT1 (VSFB1 configured for regulation) <sup>(19)</sup>                                                                                    |               | –2    |      | 18   | V    |
| 5.12               | –I <sub>VSIN</sub>                    | Output reverse current                                                                                                                                                | VSOUT1 = 14 V and VBATP = 0 V, regulator switched off                                                                                       |               | 20    |      |      | mA   |
| 5.13               | T <sub>prot</sub> I <sub>VSOUT1</sub> | Temperature protection threshold <sup>(20)</sup>                                                                                                                      |                                                                                                                                             |               | 175   |      | 210  | °C   |
| 5.14               | I <sub>VSOUT1_limit</sub>             | Current-limit                                                                                                                                                         |                                                                                                                                             |               | 120   |      | 500  | mA   |
| VOLTAGE MONITORING |                                       |                                                                                                                                                                       |                                                                                                                                             |               |       |      |      |      |
| 6.1                | VBATP_UV <sub>off</sub>               | VBATP and VBAT_SAFING level for indication by VBAT_UV comparator <sup>(21)</sup>                                                                                      | VBATP = VBAT_SAFING                                                                                                                         |               | 4.2   |      | 4.5  | V    |
| 6.2                | VBATP_UV <sub>on</sub>                | VBATP and VBAT_SAFING level for indication by VBAT_UV comparator <sup>(21)</sup>                                                                                      | VBATP = VBAT_SAFING                                                                                                                         |               | 5.4   |      | 5.8  | V    |
| 6.3                | VBATP_UV <sub>hys</sub>               | Undervoltage hysteresis                                                                                                                                               | VBATP = VBAT_SAFING                                                                                                                         |               | 1.1   |      | 1.4  | V    |
| 6.4                | VBATP_OV <sub>rise</sub>              | VBATP level for setting VBAT_OV flag <sup>(22)</sup>                                                                                                                  | VBATP = VBAT_SAFING                                                                                                                         |               | 34.7  |      | 36.7 | V    |
| 6.5                | VBATP_OV <sub>fall</sub>              | VBATP level for clearing VBAT_OV flag <sup>(23)</sup>                                                                                                                 | VBATP = VBAT_SAFING                                                                                                                         |               | 34.4  |      | 36.3 | V    |
| 6.8                | VDD5_UV                               | VDD5 undervoltage level                                                                                                                                               | VBATP = VBAT_SAFING                                                                                                                         |               | 4.5   |      | 4.85 | V    |
| 6.8a               |                                       | Hysteresis                                                                                                                                                            | VBATP = VBAT_SAFING                                                                                                                         |               | 140   |      |      | mV   |
| 6.9                | VDD5_UV <sub>head</sub>               | VDD5 undervoltage headroom (VDD5act – VDD5_UVact)                                                                                                                     | VBATP = VBAT_SAFING                                                                                                                         |               | 200   |      |      | mV   |
| 6.10               | VDD5_OV                               | VDD5 overvoltage level                                                                                                                                                | VBATP = VBAT_SAFING                                                                                                                         |               | 5.2   |      | 5.45 | V    |
| 6.10a              |                                       | Hysteresis                                                                                                                                                            | VBATP = VBAT_SAFING                                                                                                                         |               | 140   |      |      | mV   |
| 6.11               | VDD5_OV <sub>head</sub>               | VDD5 overvoltage headroom (VDD5_OVact – VDD5act)                                                                                                                      | VBATP = VBAT_SAFING                                                                                                                         |               | 200   |      |      | mV   |
| 6.12               | VDD3/5_UV                             | VDD3/5 undervoltage level                                                                                                                                             | VBATP = VBAT_SAFING                                                                                                                         | 3.3-V setting | 3     |      | 3.17 | V    |
|                    |                                       |                                                                                                                                                                       |                                                                                                                                             | 5-V setting   | 4.5   | 4.85 |      |      |
| 6.12a              |                                       | Hysteresis                                                                                                                                                            | VBATP = VBAT_SAFING                                                                                                                         | 3.3-V setting | 100   |      |      | mV   |
|                    |                                       |                                                                                                                                                                       |                                                                                                                                             | 5-V setting   | 140   |      |      |      |
| 6.13               | VDD3/5_UV <sub>head</sub>             | VDD3/5 undervoltage headroom (VDD3/5act – VDD3/5_UVact)                                                                                                               | VBATP = VBAT_SAFING                                                                                                                         | 3.3-V setting | 155   |      |      | mV   |
|                    |                                       |                                                                                                                                                                       |                                                                                                                                             | 5-V setting   | 200   |      |      |      |

(16) Referenced to VTRACK1 input, including long-term and temperature drift.

(17) VSOUT1 including line and load regulation, temperature drift and long-term drift.

(18) VSOUT1 maximum power dissipation for the internal FET must not exceed 0.6 W to avoid overtemperature. Special consideration must be taken for output voltages greater than 5 V and when VBATP is used to supply VSIN instead of VDD6.

(19) VSOUT1 is connected to VSFB1 directly (for unity gain) or through resistor divider (tracking mode gain or non-tracking mode output voltage adjusting). In case of a short to supply fault, the voltage on VSOUT1 is equal to the supply to the device (VBATP, VBAT\_SAFING, and VSIN where VSIN is connected to VBATP as it's supply instead of VDD6) and VSFB1 voltage will follow VSOUT1 based on the use case, directly (for unity gain) or via resistor divider (tracking mode gain or non-tracking mode output voltage adjusting).

(20) Protection of VSOUT1 Sensor Supply. Only VSOUT1 switch-offs off.

(21) VBATP\_UV<sub>off</sub> and VBATP\_UV<sub>on</sub> are the threshold levels for VBATP where UV will be indicated by the VBAT\_UV bit in VMON\_STAT\_1 register. The VBATP level that will allow device power up is outlined by R1.1.

(22) Brings device into the RESET state and sets flag in SPI

(23) Clears flag in SPI

## Electrical Characteristics (continued)

Over operating ambient temperature  $T_A = -40^{\circ}\text{C}$  to the maximum-operating junction temperature  $T_J = 150^{\circ}\text{C}$ , and with  $\text{VBATP} = \text{VBAT\_SAFING}$  in the recommended operating range (see R1.2 in [Section 4.3](#)) (unless otherwise noted)

| POS                      | PARAMETER                      |                                                                                                                  | TEST CONDITIONS                                                                                                                                                                                                                                                                                                                              |               | MIN       | TYP | MAX        | UNIT   |
|--------------------------|--------------------------------|------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|-----------|-----|------------|--------|
| 6.14                     | VDD3/5_OV                      | VDD5_3 overvoltage level                                                                                         | VBATP = VBAT_SAFING                                                                                                                                                                                                                                                                                                                          | 3.3-V setting | 3.43      |     | 3.6        | V      |
|                          |                                |                                                                                                                  |                                                                                                                                                                                                                                                                                                                                              | 5-V setting   | 5.2       |     | 5.5        |        |
| 6.14a                    |                                | Hysteresis                                                                                                       | VBATP = VBAT_SAFING                                                                                                                                                                                                                                                                                                                          | 3.3-V setting |           | 100 |            | mV     |
|                          |                                |                                                                                                                  |                                                                                                                                                                                                                                                                                                                                              | 5-V setting   |           | 140 |            |        |
| 6.15                     | VDD3/5_UVhead                  | VDD3/5 undervoltage headroom (VDD3/5_OVact – VDD3/5act)                                                          | VBATP = VBAT_SAFING                                                                                                                                                                                                                                                                                                                          | 3.3-V setting | 170       |     |            | mV     |
|                          |                                |                                                                                                                  |                                                                                                                                                                                                                                                                                                                                              | 5-V setting   | 200       |     |            |        |
| 6.16                     | VDD1_UV                        | VDD1 undervoltage level                                                                                          | VBATP = VBAT_SAFING. Sensed on VDD1_SENSE pin. Relative thresholds are with respect to nominal 800-mV VDD1SENSE (Pos 4.2)                                                                                                                                                                                                                    |               | 752       |     | 784        | mV     |
| 6.16a                    |                                | Hysteresis                                                                                                       | VBATP = VBAT_SAFING. Sensed on VDD1_SENSE pin. Relative thresholds are with respect to nominal 800-mV VDD1SENSE (Pos 4.2)                                                                                                                                                                                                                    |               |           | 10  |            | mV     |
| 6.17                     | VDD1_OV                        | VDD1 overvoltage level                                                                                           | VBATP = VBAT_SAFING. Sensed on VDD1_SENSE pin. Relative thresholds are with respect to nominal 800-mV VDD1SENSE (Pos 4.2)                                                                                                                                                                                                                    |               | 816       |     | 848        | mV     |
| 6.17a                    |                                | Hysteresis                                                                                                       | VBATP = VBAT_SAFING. Sensed on VDD1_SENSE pin. Relative thresholds are with respect to nominal 800-mV VDD1SENSE (Pos 4.2)                                                                                                                                                                                                                    |               |           | 9   |            | mV     |
| 6.19                     | VSOUT1_UV                      | VSOUT1 undervoltage level                                                                                        | Sensed on VSFB1 pin. Relative thresholds (ratio) are: <ul style="list-style-type: none"><li>For non-tracking mode, with respect to nominal 2.5-V VSFB1 (Pos 5.3)</li><li>For tracking mode, with respect to voltage applied on VTRACK1 pin</li><li>In tracking mode, VSOUT1_UV comparator output is valid for VTRACK1 DC condition</li></ul> |               | 0.88      |     | 0.94       | VSOUT1 |
| 6.20                     | VSOUT1_OV                      | VSOUT1 overvoltage level                                                                                         | Sensed on VSFB1 pin. Relative thresholds (ratio) are: <ul style="list-style-type: none"><li>For non-tracking mode, with respect to nominal 2.5-V VSFB1 (Pos 5.3)</li><li>For tracking mode, with respect to voltage applied on VTRACK1 pin</li><li>In tracking mode, VSOUT1_OV comparator output is valid for VTRACK1 DC condition</li></ul> |               | 1.06      |     | 1.12       | VSOUT1 |
| 6.22                     | VDD6_UV                        | VDD6 undervoltage level <sup>(24)</sup>                                                                          |                                                                                                                                                                                                                                                                                                                                              |               | 5.2       |     | 5.4        | V      |
| 6.22a                    |                                | Hysteresis                                                                                                       |                                                                                                                                                                                                                                                                                                                                              |               |           | 115 |            | mV     |
| 6.23                     | VDD6_OV                        | VDD6 overvoltage level <sup>(24)</sup>                                                                           |                                                                                                                                                                                                                                                                                                                                              |               | 7.8       |     | 8.2        | V      |
| 6.23a                    |                                | Hysteresis                                                                                                       |                                                                                                                                                                                                                                                                                                                                              |               |           | 115 |            | mV     |
| IGNITION AND CAN WAKE-UP |                                |                                                                                                                  |                                                                                                                                                                                                                                                                                                                                              |               |           |     |            |        |
| 7.1                      | IGN_WUP                        | IGN wake-up threshold <sup>(25)</sup>                                                                            | VBATP = VBAT_SAFING =12 V                                                                                                                                                                                                                                                                                                                    |               | 2         |     | 3          | V      |
| 7.2                      | CAN_WUP                        | CAN wake-up threshold <sup>(25)</sup>                                                                            | VBATP = VBAT_SAFING =12 V                                                                                                                                                                                                                                                                                                                    |               | 2         |     | 3          | V      |
| 7.3                      | WUP_hyst                       | Wake-up hysteresis                                                                                               | VBATP = VBAT_SAFING =12 V                                                                                                                                                                                                                                                                                                                    |               | 50        |     | 200        | mV     |
| 7.4                      | I_IGN                          | IGN pin forward leakage current                                                                                  | IGN pin at 36 V, VBATP = VBAT_SAFING = 12V                                                                                                                                                                                                                                                                                                   |               |           |     | 50         | μA     |
| 7.5                      | I_IGN_rev                      | IGN reverse current                                                                                              | IGN at –7 V, VBATP = VBAT_SAFING =12 V                                                                                                                                                                                                                                                                                                       |               | –1        |     |            | mA     |
| 7.7                      | I_CANWU                        | CANWU pin forward leakage current                                                                                | CANWU pin at 36 V, VBATP = VBAT_SAFING = 12V                                                                                                                                                                                                                                                                                                 |               |           |     | 50         | μA     |
| 7.8                      | I_CAN_rev                      | CANWU reverse current                                                                                            | CANWU at –0.3 V, VBATP = VBAT_SAFING =12 V                                                                                                                                                                                                                                                                                                   |               |           |     |            | mA     |
| CHARGE PUMP              |                                |                                                                                                                  |                                                                                                                                                                                                                                                                                                                                              |               |           |     |            |        |
| AN                       | C <sub>pump</sub>              | Pumping capacitor (between CP1 and CP2)                                                                          |                                                                                                                                                                                                                                                                                                                                              |               |           | 10  |            | nF     |
| AN                       | C <sub>store</sub>             | Storage capacitor (between VCP and VBATP)                                                                        |                                                                                                                                                                                                                                                                                                                                              |               |           | 100 |            | nF     |
| 8.1                      | VCP <sub>on</sub>              | VCP output voltage in on-state                                                                                   | VBATP > 5.8 V                                                                                                                                                                                                                                                                                                                                |               | VBATP + 4 |     | VBATP + 15 | V      |
| 8.2                      | I <sub>CP</sub>                | External load                                                                                                    | Load coming from R <sub>GS</sub> of Reverse Battery Protection                                                                                                                                                                                                                                                                               |               |           |     | 100        | μA     |
| 8.3                      | f <sub>CP</sub>                | Charge-pump switching frequency                                                                                  |                                                                                                                                                                                                                                                                                                                                              |               | 225       | 250 | 275        | kHz    |
| RESET AND ENABLE OUTPUTS |                                |                                                                                                                  |                                                                                                                                                                                                                                                                                                                                              |               |           |     |            |        |
| 9.1                      | V <sub>NRES_ENDRV_L</sub>      | NRES / ENDRV low-output level                                                                                    | With external 2-mA open-drain current                                                                                                                                                                                                                                                                                                        |               |           |     | 0.2        | V      |
| 9.2                      | R <sub>NRES_ENDRV_PULLUP</sub> | NRES / ENDRV internal pullup resistance                                                                          |                                                                                                                                                                                                                                                                                                                                              |               | 3         |     | 6          | kΩ     |
| 9.2a                     | R <sub>DS(on)_ENDRV_NRES</sub> | R <sub>DS(on)</sub> NRES/ENDRV pulldown transistor                                                               |                                                                                                                                                                                                                                                                                                                                              |               |           |     | 40         | Ω      |
| 9.3                      | R <sub>RSTEXT</sub>            | Value of external reset extension resistor, in case of open-connect, device stays in RESET state <sup>(26)</sup> |                                                                                                                                                                                                                                                                                                                                              |               | 0         | 22  |            | kΩ     |

(24) Information in SPI register only

(25) For device wake up, VBATP and VBAT\_SAFING must be operating range, Recommended Operating Conditions R1.1 and R1.3a, and then a level on either IGN or CANWU to allow the device to start up, especially when VBATP and VBAT\_SAFING are ramping.

(26) The maximum resistance recommend for RSTEXT to ground is 120 k $\Omega$ .

## Electrical Characteristics (continued)

Over operating ambient temperature  $T_A = -40^\circ\text{C}$  to the maximum-operating junction temperature  $T_J = 150^\circ\text{C}$ , and with  $\text{VBATP} = \text{VBAT\_SAFING}$  in the recommended operating range (see R1.2 in [Section 4.3](#)) (unless otherwise noted)

| POS                         | PARAMETER                  |                                                                           | TEST CONDITIONS                                                  | MIN         | TYP | MAX | UNIT |
|-----------------------------|----------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------|-------------|-----|-----|------|
| 9.5                         | V <sub>ENDRV_NRES_TH</sub> | ENDRV and NRES input readback <i>logic 1</i> threshold                    | Read-back muxed to DIAG_OUT pin                                  | 350         | 400 | 450 | mV   |
| DIGITAL INPUT / OUTPUT      |                            |                                                                           |                                                                  |             |     |     |      |
| 10.1                        | V <sub>DIGIN_HIGH</sub>    | Digital input, high level for NCS, SDI, SCLK, ERROR/WDI and SEL_VDD3/5    |                                                                  | 2           |     |     | V    |
| 10.2                        | V <sub>DIGIN_LOW</sub>     | Digital input, low level for NCS, SDI, SCLK, ERROR/WDI and SEL_VDD3/5     |                                                                  |             |     | 0.8 | V    |
| 10.3                        | V <sub>DIGIN_HYST</sub>    | Digital input hysteresis for NCS, SCI, SCLK and ERROR/WDI <sup>(27)</sup> |                                                                  | 0.1         |     |     | V    |
| 10.4                        | R <sub>DIAGOUT_AMUX</sub>  | Output resistance at DIAG_OUT pin in AMUX mode                            | BG1 selected on AMUX, < 200 nA current in or out of DIAG_OUT pin |             |     | 15  | kΩ   |
| 10.5                        | V <sub>DIGOUT_HIGH</sub>   | Digital output, high level <sup>(28)</sup>                                | I <sub>OUT</sub> = −2 mA (out of pin)                            | VDDIO − 0.2 |     |     | V    |
| 10.6                        | V <sub>DIGOUT_LOW</sub>    | Digital output, low level <sup>(28)</sup>                                 | I <sub>OUT</sub> = 2 mA (into pin)                               |             |     | 0.2 | V    |
| SERIAL PERIPHERAL INTERFACE |                            |                                                                           |                                                                  |             |     |     |      |
| 13.12                       | R <sub>PULL_UP</sub>       | Internal pullup resistor on NCS input pin                                 |                                                                  | 40          | 70  | 100 | kΩ   |
| 13.13                       | R <sub>PULL_DOWN</sub>     | Internal pulldown resistor on SDI and SCLK input pins                     |                                                                  | 40          | 70  | 100 | kΩ   |

(27) SEL\_VDD3/5 is sampled and latched at device power up hysteresis,  $V_{\text{DIGIN\_HYST}}$ , does not apply.

(28) For pins SDO and DIAG\_OUT in DMUX mode.

## 4.6 Timing Requirements

Over operating ambient temperature  $T_A = -40^\circ\text{C}$  to the maximum-operating junction temperature  $T_J = 150^\circ\text{C}$ , and  $\text{VBATP} = \text{VBAT\_SAFING}$  in the recommended operating range (see R1.2 in the [Section 4.3](#)) (unless otherwise noted)

| POS                                               |                           |                                                                  | MIN                                                                                       | NOM | MAX              | UNIT               |      |     |
|---------------------------------------------------|---------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------------------------|-----|------------------|--------------------|------|-----|
| VDD5 – LDO WITH INTERNAL FET                      |                           |                                                                  |                                                                                           |     |                  |                    |      |     |
| 2.12                                              | t <sub>delayVDD5</sub>    | VDD5 voltage stabilization delay                                 | Maximum delay between rising edge on CANWU pin until VDD5 reaches the end-value within 2% |     | 5                | ms                 |      |     |
| VDD3/5 – LDO WITH INTERNAL FET                    |                           |                                                                  |                                                                                           |     |                  |                    |      |     |
| 3.12                                              | t <sub>VDD3/5</sub>       | VDD3/5 voltage stabilization delay                               | Maximum delay after CANWU wakeup for VDD3/5 output to settle                              |     | 5                | ms                 |      |     |
| VDD1 – LDO WITH EXTERNAL FET                      |                           |                                                                  |                                                                                           |     |                  |                    |      |     |
| 4.15                                              | t <sub>delayVDD1</sub>    | VDD1 voltage stabilization delay                                 | Maximum delay after CANWU wakeup for VDD1 output to settle                                |     | 5                | ms                 |      |     |
| VOLTAGE MONITORING                                |                           |                                                                  |                                                                                           |     |                  |                    |      |     |
| 6.7                                               | VBATP_deglitch            | VBATP undervoltage and overvoltage monitor deglitch time         |                                                                                           |     | 180              | 240 <sup>(1)</sup> | 260  | μs  |
| 6.18                                              | VDDx_deglitch             | VDDx undervoltage and overvoltage monitor deglitch time          |                                                                                           |     | 10               |                    | 40   | μs  |
| 6.21                                              | VSOUT1_deglitch           | VSOUT1 undervoltage and overvoltage monitor deglitch time        |                                                                                           |     | 10               |                    | 40   | μs  |
| IGNITION AND CAN WAKE-UP (IGN AND CANWU)          |                           |                                                                  |                                                                                           |     |                  |                    |      |     |
| 7.6                                               | IGN_deg                   | IGN deglitch filter time                                         |                                                                                           |     | 7.5              |                    | 22   | ms  |
| 7.9                                               | CANWU_deg                 | CANWU deglitch filter time                                       |                                                                                           |     | 100              |                    | 350  | μs  |
| RESET AND ENABLE OUTPUTS                          |                           |                                                                  |                                                                                           |     |                  |                    |      |     |
| 9.4                                               | t <sub>RSTEXT(22kΩ)</sub> | Reset extension delay                                            | 22 kΩ                                                                                     |     | 4.05             | 4.5                | 4.95 | ms  |
| 9.4a                                              | t <sub>RSTEXT(0kΩ)</sub>  | Reset extension delay                                            | 0 kΩ                                                                                      |     | 0.98             | 1.4                | 1.89 | ms  |
| INTERNAL SYSTEM CLOCK                             |                           |                                                                  |                                                                                           |     |                  |                    |      |     |
| 11.1                                              | f <sub>Sysclk</sub>       | System clock frequency <sup>(2)</sup>                            |                                                                                           |     | 3.8              | 4                  | 4.2  | MHz |
| WINDOW WATCHDOG                                   |                           |                                                                  |                                                                                           |     |                  |                    |      |     |
| 12.2                                              | t <sub>WD_pulse</sub>     | Deglitch time on ERROR/WDI pin for watchdog-trigger input signal |                                                                                           |     | 14.25            | 30                 | 32   | μs  |
| SERIAL PERIPHERAL INTERFACE TIMING <sup>(3)</sup> |                           |                                                                  |                                                                                           |     |                  |                    |      |     |
| 13.1                                              | f <sub>SPI</sub>          | SPI clock (SCLK) frequency                                       | VDDIO = 3.3 V                                                                             |     | 5 <sup>(4)</sup> |                    |      | MHz |
|                                                   |                           |                                                                  | VDDIO = 5 V                                                                               |     | 6                |                    |      |     |

(1) 240  $\mu\text{s}$  for VBAT-UV deglitch and 260  $\mu\text{s}$  for VBAT-OV deglitch

(2) The system clock is also used to derive the clock for the watchdog timer, so the system clock tolerance also impacts the watchdog-timer tolerance.

(3) Capacitance at  $C_{\text{SDO}} = 100 \text{ pF}$

(4) MAX SPI Clock tolerance is  $\pm 10\%$

## Timing Requirements (continued)

Over operating ambient temperature  $T_A = -40^\circ\text{C}$  to the maximum-operating junction temperature  $T_J = 150^\circ\text{C}$ , and  $\text{VBATP} = \text{VBAT\_SAFING}$  in the recommended operating range (see R1.2 in the [Section 4.3](#)) (unless otherwise noted)

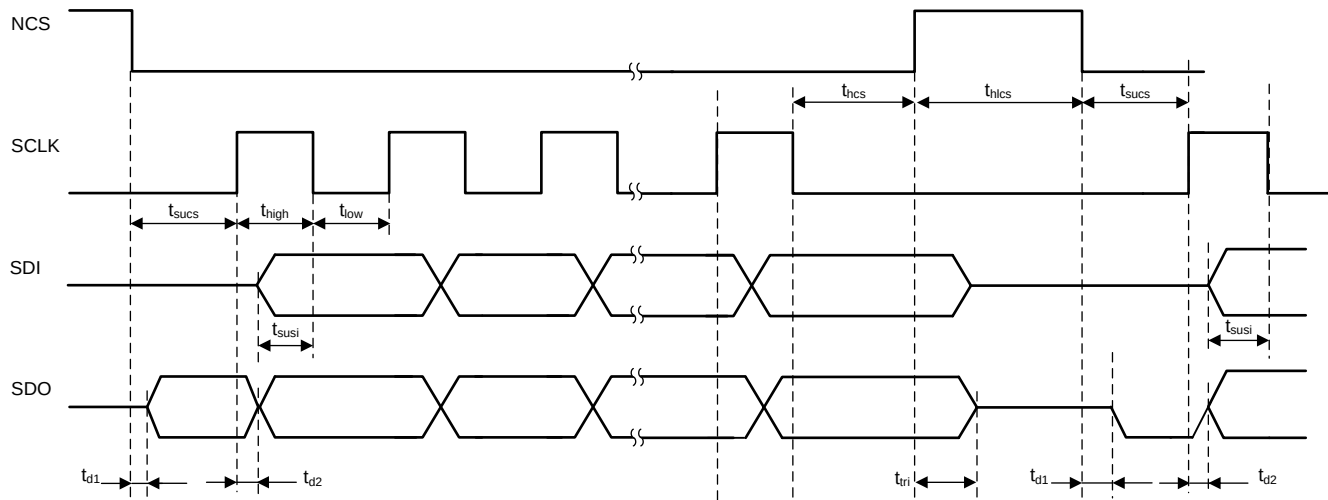
| POS   |                   |                                                                                           | MIN            | NOM  | MAX | UNIT |
|-------|-------------------|-------------------------------------------------------------------------------------------|----------------|------|-----|------|
| 13.2  | $t_{\text{SPI}}$  | SPI clock period                                                                          | VDDIO = 3.3 V  | 200  |     | ns   |
|       |                   |                                                                                           | VDDIO = 5 V    | 167  |     |      |
| 13.3  | $t_{\text{high}}$ | High time: SCLK logic high duration                                                       | See Figure 4-2 | 85.7 |     | ns   |
| 13.4  | $t_{\text{low}}$  | Low time: SCLK logic low duration                                                         |                | 45   |     | ns   |
| 13.5  | $t_{\text{sucs}}$ | Setup time NCS: time between falling edge of NCS and rising edge of SCLK                  |                | 45   |     | ns   |
| 13.7  | $t_{\text{susi}}$ | Setup time at SDI: setup time of SDI before the falling edge of SCLK                      |                | 15   |     | ns   |
| 13.9  | $t_{\text{hcs}}$  | Hold time: time between the falling edge of SCLK and rising edge of NCS                   |                | 45   |     | ns   |
| 13.10 | $t_{\text{hics}}$ | SPI transfer inactive time (time between two transfers) during which NCS must remain high |                | 788  |     | ns   |

## 4.7 Switching Characteristics

Over operating ambient temperature  $T_A = -40^\circ\text{C}$  to the maximum-operating junction temperature  $T_J = 150^\circ\text{C}$ , and  $\text{VBATP} = \text{VBAT\_SAFING}$  in the recommended operating range (see R1.2 in [Section 4.3](#)) (unless otherwise noted)

| POS                                                     | PARAMETER        | TEST CONDITIONS                                                                          | MIN            | TYP | MAX  | UNIT |
|---------------------------------------------------------|------------------|------------------------------------------------------------------------------------------|----------------|-----|------|------|
| <b>Serial Peripheral Interface Timing<sup>(1)</sup></b> |                  |                                                                                          |                |     |      |      |
| 13.6                                                    | $t_{\text{d1}}$  | Delay time: time delay from falling edge of NCS to SDO transitioning from tri-state to 0 | See Figure 4-2 |     | 53.3 | ns   |
| 13.8                                                    | $t_{\text{d2}}$  | Delay time: time delay from rising edge of SCLK to data valid at SDO                     |                | 0   | 85.7 | ns   |
| 13.11                                                   | $t_{\text{tri}}$ | Tri-state delay time: time between rising edge of NCS and SDO in tri-state               |                |     | 53.3 | ns   |

(1) Capacitance at  $C_{\text{SDO}} = 100 \text{ pF}$



**Figure 4-2. SPI Timing Parameters**

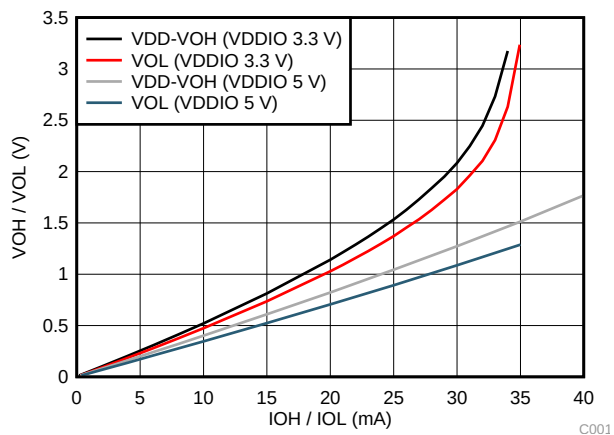


Figure 4-3. SPI SDO Buffer Source and Sink Current

## 4.8 Typical Characteristics

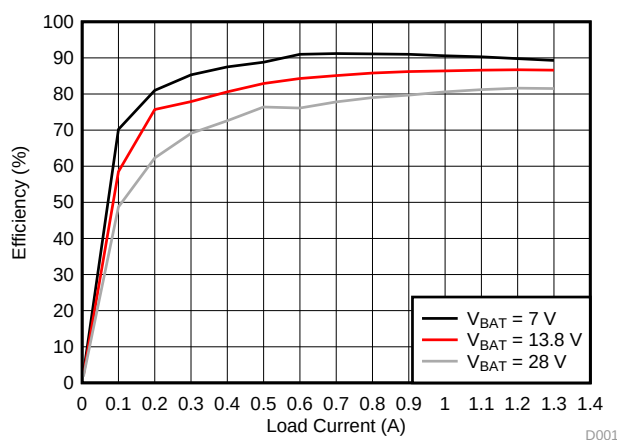


Figure 4-4. VDD6 BUCK Efficiency



## 5 Detailed Description

### 5.1 Overview

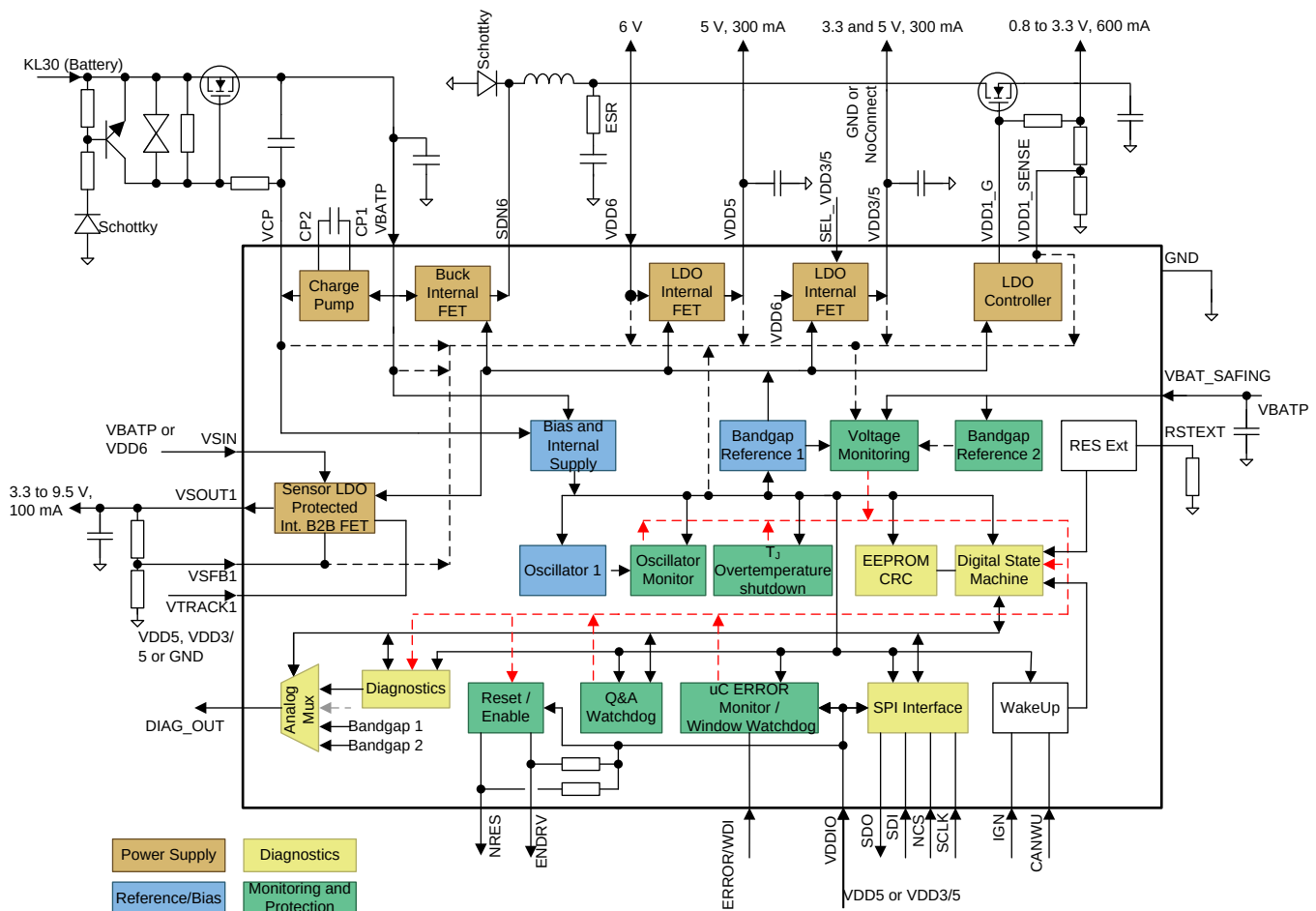
The device integrates an asynchronous-buck switch mode power-supply converter with an internal FET that converts the input battery voltage to a 6-V preregulator output, which supplies the integrated regulators.

A fixed 5-V linear regulator with an internal FET is integrated to be used as, for example, a CAN supply. A second linear regulator, also with an internal FET, regulates the 6 V to a selectable 5-V or 3.3-V MCU I/O voltage. A linear regulator controller with an external FET and resistor-divider regulates the 6 V to an externally adjustable core voltage of between 0.8 V and 3.3 V. A linear regulator with two different modes of operation (tracking mode and non-tracking mode) with adjustable voltage between 3.3 V and 9.5 V can be used as a supply for external sensor.

The device monitors undervoltage and overvoltage on all regulator outputs, battery voltage, and internal supply rails. A second band-gap reference, independent from the main band-gap reference used for regulation circuit, is used for undervoltage and overvoltage monitoring. In addition, regulator current-limits and temperature protections are implemented.

The device supports wakeup from IGNITION or wakeup from a CAN transceiver.

### 5.2 Functional Block Diagram



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## 5.3 Feature Description

### 5.3.1 VDD6 Buck Switch-Mode Power Supply

The purpose of the VDD6 buck switch-mode power supply is to reduce the power dissipation inside the device as a preregulator. The VDD6 supply regulates from the battery voltage (main supply) range to 6 V. The VDD6 output is used as the input voltage for the VDD5, VDD3/5, VDD1, and can also be used for VSOUT1 regulator depending on the required VSOUT1 output voltage. The VDD6 supply is intended as a preregulator, therefore the output accuracy of VDD6 is less than the other integrated regulators. The VDD6 current capability is set to supply the VDD5, VDD3/5, VDD1, and VSOUT1 regulators at their respective maximum output currents. Power dissipation and thermal analysis should be performed to ensure the PCB design and thermal management can support the required power dissipation in the application.

This switch-mode power supply operates with fixed-frequency adaptive on-time control PWM. The control loop is based on a hysteretic comparator. The internal N-channel MOSFET is turned on at the beginning of each cycle if the sensed voltage on the VDD6 pin is below the hysteretic comparator threshold. When the MOSFET is turned on, it is on for a minimum of 7% duty cycle (7% of  $f_{\text{clk\_VDD6}}$ ). This MOSFET is turned off when the hysteretic comparator detects a voltage on the VDD6 pin above the threshold. The VDD6 regulator may skip pulses if the output voltage remains above the hysteretic comparator when the clock edge occurs. When the MOSFET is turned off, the external Schottky diode recirculates the energy stored in the inductor for the remainder of the switching period. The VDD6 regulator enters dropout mode (100% duty cycle) for a supply voltage below approximately 7 V on the VBATP pin.

The internal MOSFET is protected from excessive power dissipation by a current-limit circuit. The VDD6 regulator also shares an overtemperature protection circuit with the VDD3/5 regulator. When overtemperature is detected by this circuit, the device transitions to the STANDBY state (all regulators switched off).

Because the control loop of the VDD6 regulator is based on a hysteretic comparator, the effective capacitance on the output, and effective series resistance (ESR) of the output capacitance must be considered. The effective capacitance of the output capacitors at the operating voltage (6 V, DC bias derating), tolerance, temperature range, and lifetime must meet the effective capacitance range for VDD6 ( $C_{\text{VDD6}}$ ). The capacitor supplier should provide the necessary derating data to calculate the effective capacitance. The hysteretic comparator also requires a specified ESR to ensure balanced operation. Typically low-ESR ceramic capacitors are used for the output, so an external resistor is required to bring the total ESR into the specified ESR range for the  $C_{\text{VDD6}}$ . A general guideline to achieve balanced operation is  $R_{\text{ESR}} = L / (15 \times C_{\text{Effective}})$ . Using a higher-effective output capacitance allows for a lower ESR, which leads to lower-voltage ripple. Additionally, the inductance influences the system: using a lower inductance value allows for lower ESR, however, the peak inductor current will be higher.

### 5.3.2 VDD5 Linear Regulator

The VDD5 pin is a regulated supply of 5 V  $\pm 2\%$  overtemperature and battery supply range. A low-ESR ceramic capacitor is required for loop stabilization. This capacitor must be placed close to the pin of the device. This output is protected against shorts to ground by a current-limit. This output also limits output-voltage overshoot during power up and during line or load transients.

On an initial IGN or CANWU power cycle, the soft-start circuit on this regulator is initiated, which is typically from 1 ms to 2 ms. This output can require a larger output capacitor to ensure that during load transients the output does not drop below the required regulation specifications.

The internal MOSFET is protected from excess power dissipation with junction-overtemperature protection. In case of an overtemperature condition in the VDD5 pin, only the VDD5 regulator switches off by clearing bit D4 in the SENS\_CTRL register. To re-enable the VDD5 pin, bit D4 in the SENS\_CTRL register must be set again.

### 5.3.3 VDD3/5 Linear Regulator

The VDD3/5 pin is a regulated supply of 3.3 V or 5 V  $\pm 2\%$  overtemperature and battery supply range. The output voltage level is selected with the SEL\_VDD3/5 pin (open pin selects 3.3 V, grounded pin selects 5 V). The state of this selection pin is sampled and latched directly at the first initial IGN or CANWU power cycle. When latched, any change in the state of this selection pin after the first initial IGN or CANWU power cycle does not change the initially selected state of the VDD3/5 regulator.

A low-ESR ceramic capacitor is required for loop stabilization. This capacitor must be placed close to the pin of the device. This output is protected against shorts to ground by a current-limit. This output also limits output-voltage overshoot during power up or during line or load transients.

On an initial IGN or CANWU power cycle, the soft-start circuit on this regulator is initiated, which is typically from 1 ms to 2 ms. This output may require a larger output capacitor to ensure that during load transients the output does NOT drop below the required regulation specifications.

The internal MOSFET is protected from excess power dissipation with a current-limit circuit and junction overtemperature protection. In case of an overtemperature in the VDD3/5 pin, the TPS65381A-Q1 device enters the STANDBY state (all regulators switched-off).

### 5.3.4 VDD1 Linear Regulator

The VDD1 pin is an adjustable regulated supply from 0.8 V to 3.3 V. This regulator uses a  $\pm 2\%$  reference (VDD1<sub>SENSE</sub>). The tolerance of the external feedback resistor divider resistors have an impact to the overall VDD1 regulation tolerance. To reduce on-chip power consumption, an external power NMOS is used. The regulation loop and the command gate drive are integrated. TI recommends applying a resistor with a value of 100 k $\Omega$  to 1 M $\Omega$  between the gate and source of the external power NMOS. The VDD1 gate output is limited to prevent gate-source overvoltage stress during power up or during line or load transients.

On an initial IGN or CANWU power cycle, the soft-start circuit on this regulator is initiated, which is typically from 1 ms to 2 ms. This soft-start is meant to prevent any voltage overshoot at start-up. The VDD1 output may require larger output capacitor to ensure that during load transients the output does not drop below the required regulation specifications.

The VDD1 LDO has no current-limit and no overtemperature protection for the external NMOS FET. Therefore, supplying the VDD1 pin from the VDD6 pin is recommended (see [Section 5.2](#)). In this way, the VDD6 pin current-limit acts as current-limit for the VDD1 pin and the power dissipation is limited also. To avoid damage in the external NMOS FET, selecting the current rating of the VDD1 pin well above the maximum-specified VDD6 current-limit is recommended.

If the VDD1 regulator is not used, leave the VDD1\_G and VDD1\_SENSE pins open. An internal pullup device on the VDD1\_SENSE pin detects the open connection and pulls up the VDD1\_SENSE pin. This forces the regulation loop to bring the VDD1\_G output down. This mechanism also masks the VDD1\_OV flag in VMON\_STAT\_2 register and therefore the ENDRV pin action from a VDD1 overvoltage (OV) condition is also masked. These actions are equivalent to clearing the NMASK\_VDD1\_UV\_OV bit in the DEV\_CFG1 register to 0. This internal pullup device on the VDD1\_SENSE pin also prevents a real VDD1 overvoltage on the MCU core supply in case of an open connection to the VDD1\_SENSE pin, as it brings the VDD1\_G pin down. Therefore, in this situation, the VDD1 output voltage is 0 V.

By default, VDD1 monitoring is disabled. If the VDD1 pin is used in the application, TI recommends to set the NMASK\_VDD1\_UV\_OV bit in the DEV\_CFG1 register to 1 when the device is in the DIAGNOSTIC state. This setting enables driving and extending the reset to the external MCU when a VDD1 undervoltage event is detected.

### 5.3.5 VSOUT1 Linear Regulator

The VSOUT1 regulator is a regulated supply with two separate modes: tracking mode and non-tracking mode. The mode selection occurs with the VTRACK1 pin. When the voltage applied on the VTRACK1 pin is above 1.2 V, the VSOUT1 pin is in tracking mode. When the VTRACK1 pin is shorted to ground, the VSOUT1 regulator is in non-tracking mode. This mode selection occurs during the first ramp-up of the VDDx rails and is latched after the first VDDx ramp-up is complete. Therefore, after completion of the VDDx ramp-up, any change on the VTRACK1 pin no longer affects the selected tracking or non-tracking mode.

In tracking mode, the VSOUT1 regulator tracks the input reference voltage on the VTRACK1 pin with a gain factor determined by the external resistive divider. The tracking offset between the VTRACK1 and VSFB1 pins is  $\pm 35$  mV. This mode allows, for instance, the VSOUT1 output voltage to be 5 V while tracking the VDD3 (3.3-V) supply. In unity-gain feedback, the VSOUT1 output voltage can directly follow the VDD5 pin or the VDD3 pin.

In non-tracking mode, the VSOUT1 output voltage is proportional to a fixed reference voltage of 2.5 V at the VSFB1 pin, with a gain factor determined by the external resistive divider. This mode allows the VSOUT1 pin to be any factor of the internal reference voltage.

Both in tracking and non-tracking mode, the VSOUT1 output voltage must be 3.3 V or higher. The VSOUT1 regulator can track the VDD3/5 pin in 3.3-V setting within the specified limits.

The VSOUT1 regulator has a separate input supply to reduce the internal power dissipation. For an output voltage of 3.3 V or 5 V, for instance, the VDD6 supply can be used as the input supply. For an output voltage greater than 5 V, the VBATP pin can be used as the input supply. The maximum power dissipation for the internal FET must not exceed 0.6 W to avoid overtemperature (thermal shutdown).

A low-ESR ceramic capacitor is required for loop stabilization; this capacitor must be placed close to the pin of the device. This supply limits output-voltage overshoot during power up or during line or load transients.

This supply rail is intended for going outside the ECU and therefore is protected against shorts to external chassis ground by a current-limit. The supply rail can be shorted externally within the specified short circuit voltages, VSOUT1<sub>SH</sub>. If the output can be shorted to voltages outside the specified short circuit voltage range, additional external protection is required.

The VSOUT1 regulator is disabled by default on start-up. After the NRES pin release, the MCU can enable the VSOUT1 regulator through a SPI command by setting bit D0 in the SENS\_CTRL register. After this SPI command, the soft-start circuit on this regulator is initiated, which is typically from 1 ms to 2 ms. This output may require a larger output capacitor to ensure that during load transients the output does NOT drop below the required regulation specifications. Regardless of tracking or non-tracking mode, the VSFB1 pin is ramped to the desired value after completion of the soft start.

The internal MOSFET is protected from excess power dissipation with a current-limit circuit and junction-temperature protection. In case of an overtemperature condition in the VSOUT1 pin, only the VSOUT1 regulator is switched off by clearing bit 0 in the SENS\_CTRL register. To re-enable the VSOUT1 pin, first bit 2 in the SAFETY\_STAT 1 register must be cleared on read-out, and afterwards bit 0 in the SENS\_CTRL register must be set again.

The VSOUT1 pin voltage can be observed by the ADC input of the MCU through the DIAG\_OUT pin (see [Section 5.4.9](#)), which allows the detection of a short to any other supply prior to enabling the VSOUT1 LDO.

### NOTE

The VSOUT1\_EN bit is in the SENS\_CTRL register which is only reinitialized by a power-on reset (NPOR) event and not a transition through the RESET state. If the VSOUT1\_EN bit was previously set to 1, it remains set to 1 and the VSOUT1 regulator remains enabled after events that cause a transition to the RESET state. In a fault case that would cause an undervoltage or overvoltage on the VSOUT1 pin, when a BIST runs automatically on the transition from the RESET to the DIAGNOSTIC state, the VSOUT1\_UV or VSOUT1\_OV condition during the BIST run would cause the device to go to the SAFE state because of the detected ABIST\_ERR.

## 5.3.6 Charge Pump

The charge pump is used to generate an overdrive voltage from the VBATP supply that is used for driving the gates of the internal NMOS FETs in the VDDx and VSOUT1 supply rails. The charge pump is a hysteretic architecture, when the VCP voltage is high enough, the CP\_OV bit sets and the charge pump stops pumping until the VCP voltage drops below the threshold, the CP\_OV bit clears and the charge pump starts pumping again. The charge pump overdrive is provided internally to the device through the linear regulators, VCP12 and VCP17. Furthermore, this overdrive voltage can drive the gate of an external NMOS FET acting as reverse-battery protection. Such reverse-battery protection allows for lower battery voltage operation compared to a traditional reverse battery-blocking diode. When using the charge pump (VCP) to drive the gate of an NMOS for reverse battery protection, a series resistance of about 10 kΩ must be connected between the VCP pin and the gate of the NMOS FET (see [Section 5.2](#)). This series resistance is required to limit any current out of the VCP pin when the gate of the NMOS FET is driven to a negative voltage, because the absolute maximum rating of the VCP pin is limited to –0.3 V because of a parasitic reverse diode to the substrate (ground).

The charge pump requires two external capacitors, one pumping capacitor ( $C_{\text{pump}}$ ) and one storage capacitor ( $C_{\text{store}}$ ). To have sufficient overdrive voltage out of the charge pump even at low battery voltage, the external load current on the VCP pin must be less than 100 μA.

## 5.3.7 Wake-Up

The TPS65381A-Q1 device has two wake-up pins: IGN and CANWU. Both pins have a wake-up threshold level from 2 V to 3 V, and a hysteresis from 50 mV to 200 mV.

The IGN wake-up pin is level-sensitive and is deglitched with the IGN\_deg deglitch (filter) time. The TPS65381A-Q1 device provides a power-latch function (POST\_RUN) for this IGN pin, allowing the MCU to decide when to power down the TPS65381A-Q1 device through SPI command. For this, the MCU must set the IGN power-latch bit 4 (IGN\_PWRL) in the SPI SAFETY\_FUNC\_CFG register, and read the unlatched status of the deglitched (filtered) IGN pin on the SPI register, DEV\_STAT, bit 0 (IGN). To enter the STANDBY state, the MCU must clear the IGN\_PWRL bit. For this, the TPS65381A-Q1 device must be in the DIAGNOSTIC state because this SPI register is only writable in the DIAGNOSTIC state. The IGN\_PWRL bit is also cleared after a detected CANWU wake-up event. Furthermore, the TPS65381A-Q1 device provides an optional transition to the RESET state after a detected IGN wake-up during POST\_RUN (see [Figure 5-2](#)).

The CANWU pin is level sensitive and is deglitched with CANWU\_deg (filter) time. The deglitched (filtered) CANWU wake-up signal is latched, into CANWU\_L, allowing the MCU to decide when to power down the TPS65381A-Q1 device through the WR\_CAN\_STBY SPI command.

### NOTE

The WR\_CAN\_STBY command should not be written to the device while the CANWU pin or IGN pin is still high. The device starts to transition to the STANDBY state and immediately transitions to the RESET state because of the wake-up request received on the CANWU or IGN pin. The registers are reinitialization according to post LBIST (because of a RESET transition) or according to NPOR (because of a STANDBY transition).

Both the IGN and CANWU pins are high voltage pins. If the pins are connected to lines with transients, the application should provide proper filtering and protection to ensure the pins stay within the specified voltage range.

---

**NOTE**

If the application does not require wake up from IGN (ignition or KL15) or wake up from CANWU (a CAN or other transceiver), but the device should wake up any time power is supplied, one method is to connect the IGN pin to the VBATP pin (and VBAT\_SAFING) through a 10-k $\Omega$  or greater series resistor. When the VBATP supply is turned on, the IGN pin also goes high and allows the device to wake up (power up) as soon as the voltage levels allow the release of NPOR circuits for the VBATP and VBAT\_SAFING pins, and the IGN pin is high.

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### 5.3.8 Reset Extension

During a power-up event, the TPS65381A-Q1 device releases the reset to the external MCU through the NRES pin with a certain delay time (reset extension time) after the VDD3/5 and VDD1 pins have crossed the respective undervoltage thresholds.

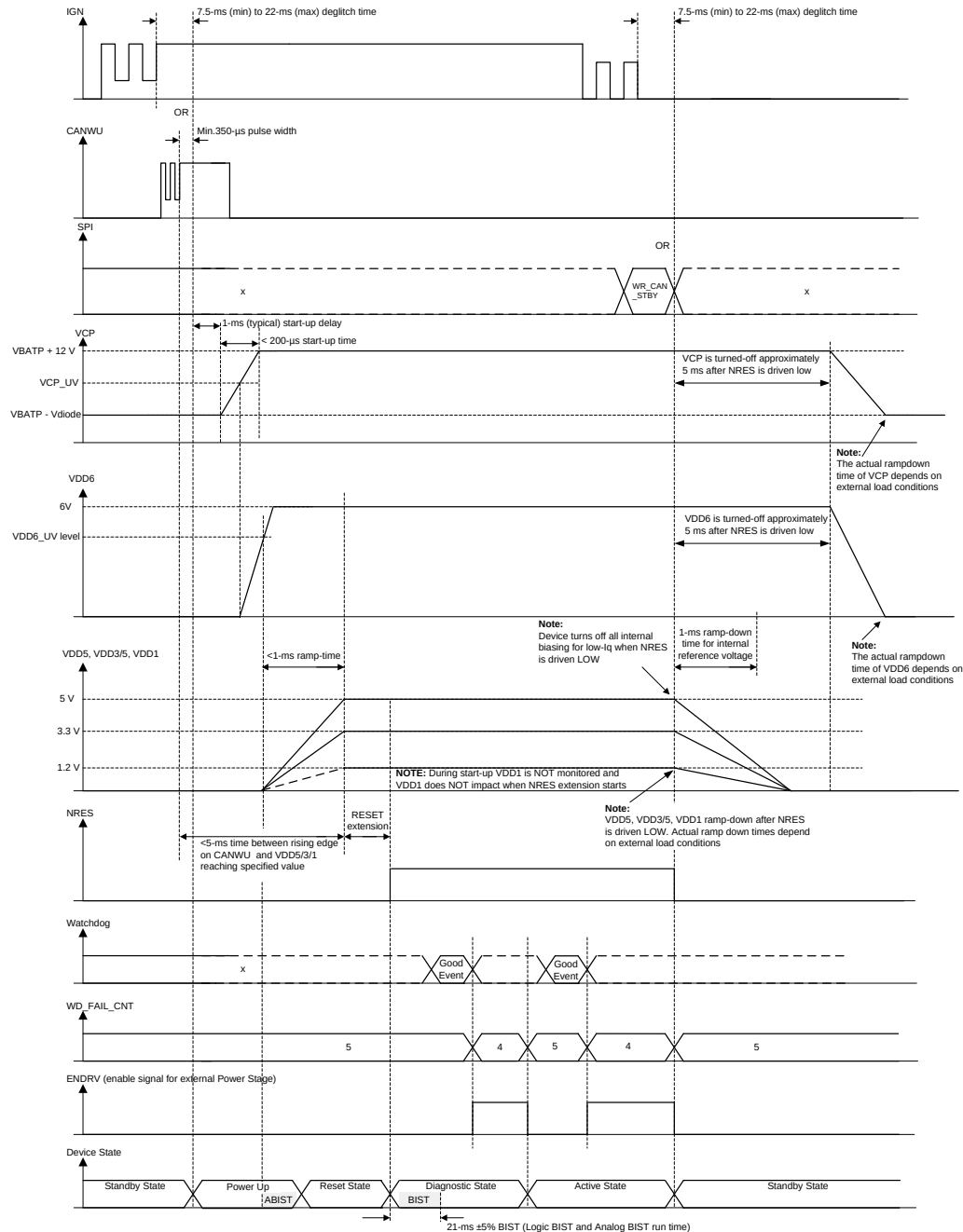
This reset extension time is externally configurable with a resistor between the RESEXT pin and ground. When shorting the RESEXT pin to ground, the minimum reset extension time is typically 1.4 ms. For a 22-k $\Omega$  external resistor, the typical reset extension time is 4.5 ms.



## 5.4 Device Functional Modes

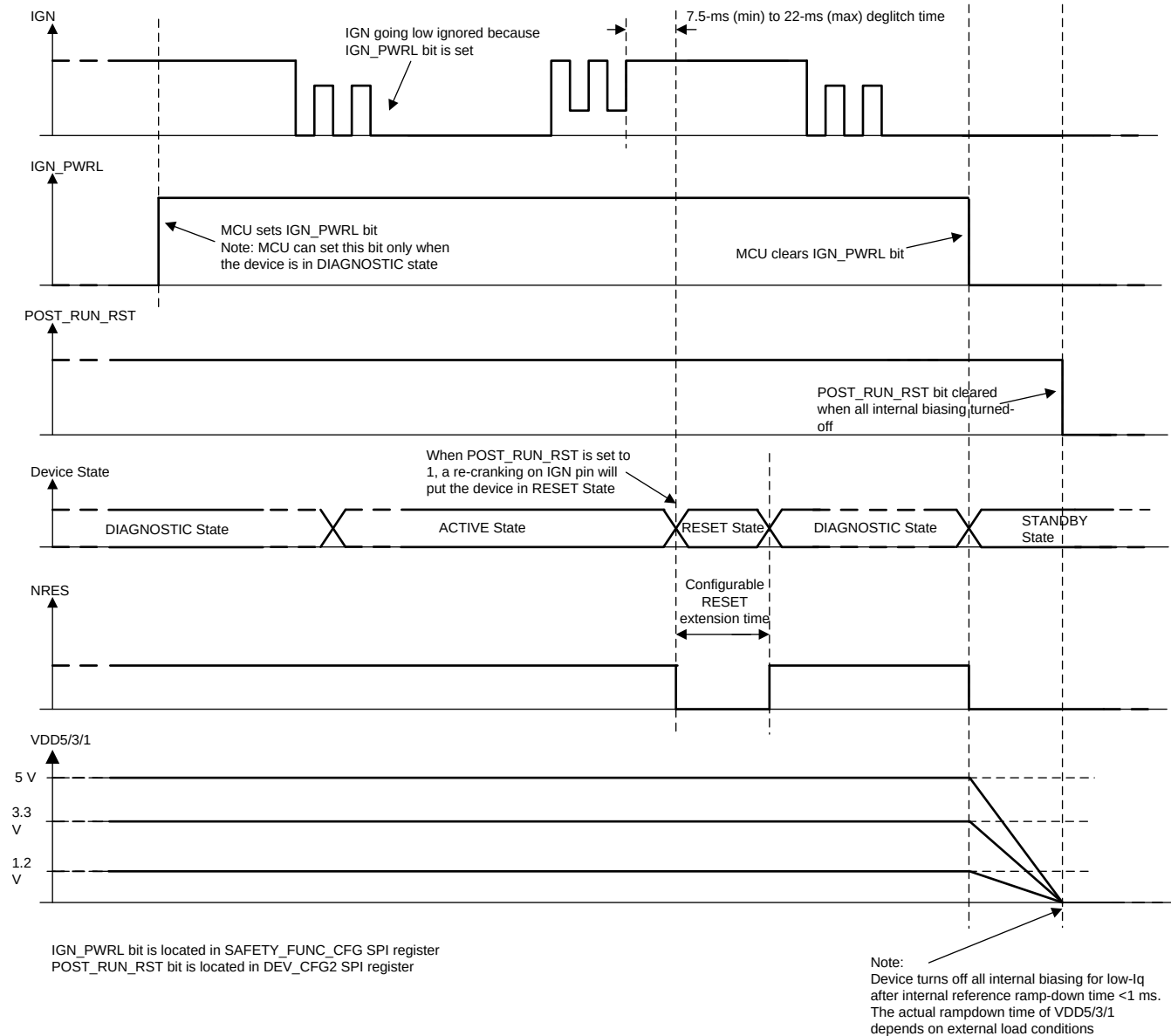
### 5.4.1 Power-Up and Power-Down Behavior

Figure 5-1 shows the power-up and power-down behavior.



- During a power-up event, the analog BIST (ABIST) begins automatically after the VDD6 rail ramps above the UV threshold. If the ABIST fails, the device transitions to the SAFE state.
- The device may not be able to respond to MCU SPI communication during a BIST, so if the MCU boots faster than the BIST, it should wait until the BIST is complete to use SPI communication. If the ABIST, LBIST, or both fail, the device transitions to the SAFE state.
- The level of the ENDRV pin depends on the watchdog failure counter, WD\_FAIL\_CNT[2:0], the ENABLE\_DRV bit, and the signals shown in Figure 5-14. The MCU should only set the ENABLE\_DRV bit when the WD\_FAIL\_CNT[2:0] counter is below 5.

Figure 5-1. Power-Up and Power-Down Behavior



- (1) Under slow VBAT ramp-down and when the VDD3/5 rail is configured as a 5-V rail, the NRES output can be pulled low when VBAT is at approximately 6.3 V. This occurs because of an undervoltage transient on VDD3/5 rail.
- (2) Under slow VBAT ramp-up and when the VDD3/5 rail is configured as a 5-V rail, the NRES output can be pulled low when VBAT is at approximately 6.6 V. This occurs because of an undervoltage transient on VDD3/5 rail.
- (3) Under similar conditions, undervoltage transients are observed on VDD5 and VSOUT1 rails.

**Figure 5-2. IGN Power Latch and POST-RUN Reset**



### 5.4.2 Safety Functions and Diagnostics Overview

The TPS65381A-Q1 device is intended for use in automotive and industrial safety-relevant applications. The following list of monitoring and protection blocks are those that improve the diagnostic coverage and decrease the undetected fault rate:

- Voltage monitor (VMON)
- Analog built-in self-test (ABIST) diagnostics for safety analog blocks
- Logic built-in self-test (LBIST) for safety controller functions
- Loss-of-clock monitor (LCMON)
- Junction temperature monitoring for all power supplies with internal FET
- Current-limit for all power supplies
- Analog MUX (AMUX) for externally monitored diagnostics and debug
- Digital MUX (DMUX) for externally monitored diagnostics and debug
- Watchdog configurable for trigger mode (open and close window) or question and answer mode
- MCU error signal monitor (ESM) for monitoring the error output from functional safety architecture MCUs
- Controlled and protected enable output (ENDRV) for external power stages or peripheral wakeup
- Device configuration register CRC protection
- SPI command decoder with parity check
- SPI data output feedback check
- Reset circuit for initializing external MCU
- EEPROM analog trim content CRC protection
- Device state controller with SAFE state in case of detected error event

### 5.4.3 Voltage Monitor (VMON)

The VBAT supply voltage, all regulator outputs, and internally generated voltages are supervised by a voltage monitor module (VMON). An undervoltage or overvoltage condition is indicated by the corresponding VMON register status flag bits:

- VMON flag bit cleared to 0 when power supply is within specification
- VMON flag bit set to 1 when power supply is outside tolerance band

The monitoring occurs by undervoltage and overvoltage comparators. The reference voltage (BANDGAP\_REF2) for the VMON module is independent of the system reference voltage (BANDGAP\_REF1) used by the regulators. A glitch-filtering function ensures reliable monitoring without false setting of the VMON status flag bits. The complete VMON block is supplied by a separate supply pin, VBAT\_SAFING.

The VMON comparator diagnostics are covered by the ABIST executed during device startup and power up or activated with the SPI command by the external MCU SPI request when the device is in the DIAGNOSTIC or ACTIVE state. Each monitored voltage rail is emulated for undervoltage and overvoltage conditions on the corresponding comparator inputs, therefore forcing the corresponding comparator to toggle multiple times (in a toggling pattern observed and checked by the ABIST controller). The monitored voltage rails themselves are not affected during this self-test, so no real undervoltage or overvoltage event occurs on any of these rails because of this self-test.

[Table 5-1](#) lists an overview of the performed voltage monitoring. As listed in this table, an overvoltage protection is implemented for some of the internal supply rails.

**Table 5-1. Voltage Monitoring Overview<sup>(1)</sup>**

| VOLTAGE<br>RAIL       | OUTPUT VOLTAGE                                              | CREATED<br>FROM<br>REFERENCE | MONITORING DETECTION<br>THRESHOLDS |                       | MONITORED AGAINST<br>REFERENCE | MONITORED<br>PIN                     | OV PROTECTION<br>LEVEL | OV<br>PROTECTION<br>REFERENCE | IMPACT ON DEVICE BEHAVIOR                                                                  |                                                                                                            |
|-----------------------|-------------------------------------------------------------|------------------------------|------------------------------------|-----------------------|--------------------------------|--------------------------------------|------------------------|-------------------------------|--------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
|                       |                                                             |                              | UV                                 | OV                    |                                |                                      |                        |                               | UV                                                                                         | OV                                                                                                         |
| SUPPLY INPUT          |                                                             |                              |                                    |                       |                                |                                      |                        |                               |                                                                                            |                                                                                                            |
| VBAT                  | N/A                                                         | N/A                          | 4.2 to 4.5 V                       | 34.7 to 36.7 V        | VMON_BG                        | VBATP                                | N/A                    | N/A                           | SPI flag VMON_STAT_1 D6<br>STANDBY state<br>NRES = 0, ENDRV = 0                            | SPI flag VMON_STAT_1 D7<br>RESET state (when<br>MASK_VBATP_OV = 0)                                         |
| SUPPLY OUTPUTS        |                                                             |                              |                                    |                       |                                |                                      |                        |                               |                                                                                            |                                                                                                            |
| VDD6                  | 6 V ± 10%                                                   | MAIN_BG                      | 5.2 to 5.4 V                       | 7.8 to 8.2 V          | VMON_BG                        | VDD6                                 | N/A                    | N/A                           | SPI flag VMON_STAT_2 D6                                                                    | SPI flag VMON_STAT_2 D7                                                                                    |
| VDD5                  | 5 V ± 2%                                                    | MAIN_BG                      | 4.5 to 4.85 V                      | 5.2 to 5.45 V         | VMON_BG                        | VDD5                                 | N/A                    | N/A                           | SPI flag VMON_STAT_2 D4                                                                    | SPI flag VMON_STAT_2 D5<br>ENDRV = 0                                                                       |
| VDD3/5 (5 V)          | 5 V ± 2%                                                    | MAIN_BG                      | 4.5 to 4.85 V                      | 5.2 to 5.5 V          | VMON_BG                        | VDD3/5                               | N/A                    | N/A                           | SPI flag VMON_STAT_2 D2<br>RESET state<br>NRES = 0, ENDRV = 0                              | SPI flag VMON_STAT_2 D3<br>ENDRV = 0                                                                       |
| VDD3/5 (3.3 V)        | 3.3 V ± 2%                                                  |                              | 3 to 3.17 V                        | 3.43 to 3.6 V         |                                |                                      |                        |                               |                                                                                            |                                                                                                            |
| VDD1                  | 0.8 V to 3.3 V –1% to +2%<br>VDD1_SENSE = 800 mV –1% to +2% | MAIN_BG                      | 0.94 to 0.98 × VDD1                | 1.03 to 1.06 × VDD1   | VMON_BG                        | VDD1_SENSE                           | N/A                    | N/A                           | SPI flag VMON_STAT_2 D0<br>RESET state<br>NRES = 0, ENDRV = 0<br>(when NMASK_VDD1_UV_OV=1) | SPI flag VMON_STAT_2 D1<br>ENDRV = 0<br>(when<br>NMASK_VDD1_UV_OV=1)                                       |
| VSOUT1 (non-tracking) | 3.3 V to 9.5 V ± 2%<br>VDSFB1 = 2.5 V ± 2%                  | MAIN_BG                      | 0.88 to 0.94 × VSOUT1              | 1.06 to 1.12 × VSOUT1 | MAIN_BG                        | VSFB1                                | N/A                    | N/A                           | SAFETY_STAT1 D5                                                                            | SPI flag SAFETY_STAT1 D4                                                                                   |
| VSOUT1 (tracking)     | 3.3 V to 9.5 V ± 2%<br>VDSFB1 = VTRACK1 ± 20 mV             | VTRACK1                      |                                    |                       | VTRACK1                        | VSFB1                                | N/A                    | N/A                           |                                                                                            |                                                                                                            |
| INTERNAL SUPPLIES     |                                                             |                              |                                    |                       |                                |                                      |                        |                               |                                                                                            |                                                                                                            |
| VCP17                 | 17 V (typ)                                                  | MAIN_BG                      | N/A                                | 27 V (typ)            | VMON_BG                        | N/A                                  | 27 V (typ)             | VMON_BG                       | N/A                                                                                        | SPI flag VMON_STAT_1 D5 –<br>STANDBY state<br>NRES = 0, ENDRV = 0                                          |
| VCP12                 | 12 V (typ)                                                  | MAIN_BG                      | 7.43 V (typ)                       | 14.2 V (typ)          | VMON_BG                        | N/A                                  | 14.2 V (typ)           | VMON_BG                       | SPI flag VMON_STAT_1 D3                                                                    | SPI flag VMON_STAT_1 D4<br>VDD5, VDD3/5 and VDD1 not<br>operational → STANDBY state<br>NRES = 0, ENDRV = 0 |
| AVDD                  | 6.9 V (typ)                                                 | Internal LV Zener            | 3.6 V (typ)                        | N/A                   | Independent local band gap     | N/A                                  | NA                     | Internal MV Zener             | NPOR → STANDBY state<br>NRES = 0, ENDRV = 0                                                | No Change                                                                                                  |
| AVDD_VMON             | 6.9 V (typ)                                                 | Internal LV Zener            | 3.56 V (typ)                       | N/A                   | Independent local band gap     | Indirectly monitoring<br>VBAT_SAFING | < 10.48 V              | Internal MV Zener             | SPI flag VMON_STAT_1 D2 →<br>NPOR → STANDBY state<br>NRES = 0, ENDRV = 0                   | SPI flag VMON_STAT_1 D2 –<br>NPOR → STANDBY state<br>NRES = 0, ENDRV = 0                                   |
| DVDD                  | 3 V (typ)                                                   | MAIN_BG                      | 2.472 V (typ)                      | 3.501 V (typ)         | VMON_BG                        | N/A                                  | N/A                    | N/A                           | NPOR → STANDBY state<br>NRES = 0, ENDRV = 0                                                | NPOR → STANDBY state<br>NRES = 0, ENDRV = 0                                                                |
| INTERNAL REFERENCES   |                                                             |                              |                                    |                       |                                |                                      |                        |                               |                                                                                            |                                                                                                            |
| MAIN_BG               | 2.5 V ± 2%                                                  | MAIN_BG                      | 2.364 V (typ)                      | 2.617 V (typ)         | VMON_BG                        | N/A                                  | N/A                    | N/A                           | STANDBY state<br>NRES = 0, ENDRV = 0                                                       | STANDBY state<br>NRES = 0, ENDRV = 0                                                                       |
| VMON_BG               | 2.5 V ± 2%                                                  | VMON_BG                      | 2.364 V (typ)                      | 2.617 V (typ)         | MAIN_BG                        | N/A                                  | N/A                    | N/A                           | STANDBY state<br>NRES = 0, ENDRV = 0                                                       | STANDBY state<br>NRES = 0, ENDRV = 0                                                                       |

(1) N/A = Not applicable

## 5.4.4 TPS65381A-Q1 Internal Error Signals

Table 5-2 lists a useful overview of the TPS65381A-Q1 device internal error signals and the impact of the signals on the device behavior.

**Table 5-2. Internal Error Signals**

| DETECTIVE CONDITION (THRESHOLD LEVEL) |             |                                                                            |      |                                               |      |      |                 | DEGLITCH TIME TO SET FLAG (μs) |     |     |                 | DEVICE STATE WHEN FLAG IS SET                                                                   |                                                                                                  |                                                                                            |
|---------------------------------------|-------------|----------------------------------------------------------------------------|------|-----------------------------------------------|------|------|-----------------|--------------------------------|-----|-----|-----------------|-------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| DMUX POS. NO.                         | SIGNAL NAME | DESCRIPTION                                                                | MIN  | TYP                                           | MAX  | UNIT | ELEC. CHAR. NO. | MIN                            | TYP | MAX | ELEC. CHAR. NO. | NRES                                                                                            | ENDRV                                                                                            | DEVICE STATE                                                                               |
| D1.2                                  | NAVDD_UV    | AVDD undervoltage comparator output (inverted)                             |      | 3.6                                           |      | V    |                 | 15                             |     | 30  |                 | LOW                                                                                             | LOW                                                                                              | STANDBY                                                                                    |
| D1.3                                  | BG_ERR1     | VMON or main band gap is OFF (set to 1 when VMON band gap > main band gap) |      | Main band gap = 2.364 (VMON band gap = 2.477) |      | V    |                 | 15                             |     | 30  |                 | LOW                                                                                             | LOW                                                                                              | STANDBY                                                                                    |
| D1.4                                  | BG_ERR2     | VMON or main band gap is OFF (set to 1 when VMON band gap < main band gap) |      | Main band gap = 2.617 (VMON band gap = 2.477) |      | V    |                 | 15                             |     | 30  |                 | LOW                                                                                             | LOW                                                                                              | STANDBY                                                                                    |
| D1.5                                  | NVCP12_UV   | VCP12 charge pump undervoltage comparator (inverted)                       |      | 7.43                                          |      | V    |                 | 15                             |     | 30  |                 | Not changed                                                                                     | Not changed                                                                                      | Not changed                                                                                |
| D1.6                                  | VCP12_OV    | VCP12 charge-pump overvoltage comparator                                   |      | 14.2                                          |      | V    |                 | 15                             |     | 30  |                 | LOW                                                                                             | LOW                                                                                              | STANDBY                                                                                    |
| D1.7                                  | VCP17_OV    | VCP17 charge-pump overvoltage comparator                                   |      | 21                                            |      | V    |                 | 15                             |     | 30  |                 | LOW                                                                                             | LOW                                                                                              | STANDBY                                                                                    |
| D1.8                                  | NVDD6_UV    | VDD6 undervoltage comparator (inverted)                                    | 5.2  |                                               | 5.4  | V    | 6.22            | 10                             |     | 40  | 6.18            | Not changed                                                                                     | Not changed                                                                                      | Not changed                                                                                |
| D1.9                                  | VDD6_OV     | VDD6 overvoltage comparator                                                | 7.8  |                                               | 8.2  | V    | 6.23            | 10                             |     | 40  | 6.18            | Not changed                                                                                     | Not changed                                                                                      | Not changed                                                                                |
| D1.10                                 | NVDD5_UV    | VDD5 undervoltage comparator (inverted)                                    | 4.5  |                                               | 4.85 | V    | 6.8             | 10                             |     | 40  | 6.18            | Not changed                                                                                     | Not changed                                                                                      | Not changed                                                                                |
| D1.11                                 | VDD5_OV     | VDD5 overvoltage comparator                                                | 5.2  |                                               | 5.45 | V    | 6.10            | 10                             |     | 40  | 6.18            | Not changed                                                                                     | LOW                                                                                              | Not changed                                                                                |
| D1.12                                 | NVDD3/5_UV  | VDD3/5 undervoltage comparator; 3.3-V setting (inverted)                   | 3    |                                               | 3.17 | V    | 6.12            | 10                             |     | 40  | 6.18            | LOW                                                                                             | LOW                                                                                              | RESET                                                                                      |
|                                       |             | VDD3/5 undervoltage comparator; 5-V setting (inverted)                     | 4.5  |                                               | 4.85 |      |                 |                                |     |     |                 |                                                                                                 |                                                                                                  |                                                                                            |
| D1.13                                 | VDD3/5_OV   | VDD3/5 overvoltage comparator; 3.3-V setting                               | 3.43 |                                               | 3.6  | V    | 6.14            | 10                             |     | 40  | 6.18            | Not changed                                                                                     | LOW                                                                                              | Not changed                                                                                |
|                                       |             | VDD3/5 overvoltage comparator; 5-V setting                                 | 5.2  |                                               | 5.5  |      |                 |                                |     |     |                 |                                                                                                 |                                                                                                  |                                                                                            |
| D1.14                                 | NVDD1_UV    | VDD1 undervoltage comparator (inverted)                                    | 0.94 |                                               | 0.98 | VDD1 | 6.16            | 10                             |     | 40  | 6.18            | Not changed when NMASK_VDD1_UV_OV = 0 (default config)<br>When NMASK_VDD1_UV_OV = 1: NRES = LOW | Not changed when NMASK_VDD1_UV_OV = 0 (default config)<br>When NMASK_VDD1_UV_OV = 1: ENDRV = LOW | Not changed when NMASK_VDD1_UV_OV = 0 (default config)<br>When NMASK_VDD1_UV_OV = 1: RESET |
| D1.15                                 | VDD1_OV     | VDD1 overvoltage comparator                                                | 1.03 |                                               | 1.06 | VDD1 | 6.17            | 10                             |     | 40  | 6.18            | Not changed                                                                                     | Not changed (default config)<br>When MASK_VDD1_UV_OV = 1: ENDRV = LOW                            | Not changed                                                                                |

Table 5-2. Internal Error Signals (continued)

| DETECTIVE CONDITION (THRESHOLD LEVEL) |               |                                                |                                                      |           |      |        |                 | DEGLITCH TIME TO SET FLAG (μs) |     |       |                 | DEVICE STATE WHEN FLAG IS SET                                     |                                                                    |                                                                                                                                                                      |
|---------------------------------------|---------------|------------------------------------------------|------------------------------------------------------|-----------|------|--------|-----------------|--------------------------------|-----|-------|-----------------|-------------------------------------------------------------------|--------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DMUX POS. NO.                         | SIGNAL NAME   | DESCRIPTION                                    | MIN                                                  | TYP       | MAX  | UNIT   | ELEC. CHAR. NO. | MIN                            | TYP | MAX   | ELEC. CHAR. NO. | NRES                                                              | ENDRV                                                              | DEVICE STATE                                                                                                                                                         |
| D1.16                                 | LOCLK         | Loss-of-system-clock comparator                | 0.742                                                |           | 2.64 | MHz    |                 | 0.379                          |     | 1.346 |                 | LOW                                                               | LOW                                                                | STANDBY                                                                                                                                                              |
| D3.4                                  | CP_OV         | Charge-pump overvoltage comparator             |                                                      | VBAT + 12 |      | V      |                 | N/A                            | N/A | N/A   |                 | Not changed                                                       | Not changed                                                        | Not changed                                                                                                                                                          |
| D3.5                                  | NCP_UV        | Charge-pump undervoltage comparator (inverted) |                                                      | VBAT + 6  |      | V      |                 | N/A                            | N/A | N/A   |                 | Not changed                                                       | Not changed                                                        | Not changed                                                                                                                                                          |
| D3.8                                  | CP_DIFF3V     | Indicates VCP-VBATP > 3 V                      |                                                      | VBAT + 3  |      | V      |                 | N/A                            | N/A | N/A   |                 | Not changed                                                       | Not changed                                                        | Not changed                                                                                                                                                          |
| D3.10                                 | NVBAT_UV      | VBAT undervoltage comparator (inverted)        | 4.2                                                  |           | 4.5  | V      | 6.1             |                                | 200 |       | 6.7             | LOW                                                               | LOW                                                                | STANDBY                                                                                                                                                              |
| D3.11                                 | VBATP_OV      | VBAT overvoltage comparator                    | 34.7                                                 |           | 36.7 | V      | 6.5             |                                | 200 |       | 6.7             | LOW (default config)<br>When MASK_VBATP_OV = 1:<br>NRES unchanged | LOW (default config)<br>When MASK_VBATP_OV = 1:<br>ENDRV unchanged | RESET (default config)<br>When MASK_VBATP_OV = 1:<br>device state unchanged                                                                                          |
| D3.12                                 | VDD5_OT       | VDD5 overtemperature                           | 175                                                  |           | 210  | °C     | 3.13            | 45                             |     | 64    |                 | LOW                                                               | LOW                                                                | Device state depends on NMASK_VDD5_OT bit setting:<br>NMASK_VDD5_OT = 0 :<br>no impact to device state<br>NMASK_VDD5_OT = 1 :<br>VDD5 disabled → RESET               |
| D3.13                                 | VDD3/5_OT     | VDD3/5 overtemperature                         | 175                                                  |           | 210  | °C     | 2.13            | 45                             |     | 64    |                 | LOW                                                               | LOW                                                                | Device state depends on NMASK_VDD3/5_OT bit setting:<br>NMASK_VDD3/5_OT = 0 :<br>VDD3/5 disabled →<br>VDD3/5 UV event →<br>RESET<br>NMASK_VDD3/5_OT = 1 :<br>STANDBY |
| D3.14                                 | VSOUT1_OT     | VSOUT1 overtemperature                         | 175                                                  |           | 210  | °C     | 5.13            | 45                             |     | 64    |                 | Not changed                                                       | Not changed                                                        | Not changed                                                                                                                                                          |
| D3.15                                 | VDD5_CL       | VDD5 current-limit <sup>(1)</sup>              | 350                                                  |           | 650  | mA     | 2.14            | 15                             |     | 30    |                 | Not changed                                                       | Not changed                                                        | Not changed                                                                                                                                                          |
| D3.16                                 | VDD3/5_CL     | VDD3/5 current-limit                           | 350                                                  |           | 650  | mA     | 3.14            | 15                             |     | 30    |                 | Not changed                                                       | Not changed                                                        | Not changed                                                                                                                                                          |
| D4.2                                  | VSOUT1_CL     | VSOUT1 current-limit                           | 100                                                  |           | 500  | mA     | 5.19            | 15                             |     | 30    |                 | Not changed                                                       | Not changed                                                        | Not changed                                                                                                                                                          |
| D4.3                                  | NVSOUT1_UV    | VSOUT1 undervoltage comparator (inverted)      | 0.88                                                 |           | 0.94 | VSOUT1 | 6.19            | 10                             |     | 40    | 6.21            | Not changed                                                       | Not changed                                                        | Not changed                                                                                                                                                          |
| D4.4                                  | VSOUT1_OV     | VSOUT1 overvoltage comparator                  | 1.06                                                 |           | 1.12 | VSOUT1 | 6.20            | 10                             |     | 40    | 6.21            | Not changed                                                       | Not changed                                                        | Not changed                                                                                                                                                          |
| D4.5                                  | NDVDD_UV      | DVDD undervoltage comparator (inverted)        |                                                      | 2.472     |      | V      |                 |                                | 0   |       |                 | LOW                                                               | LOW                                                                | STANDBY                                                                                                                                                              |
| D4.6                                  | DVDD_OV       | DVDD overvoltage comparator                    |                                                      | 3.501     |      | V      |                 |                                | 0   |       |                 | LOW                                                               | LOW                                                                | STANDBY                                                                                                                                                              |
| D4.8                                  | VS_TRK_MODE   | VSOUT1 in track-mode indication                |                                                      | 1.2       |      | V      | 5.3a            | N/A                            | N/A | N/A   |                 | Not changed                                                       | Not changed                                                        | Not changed                                                                                                                                                          |
| D4.9                                  | VMON_TRIM_ERR | VMON trim error                                | Set when bit-flip in VMON trim registers is detected |           |      |        |                 | 5                              |     | 10    |                 | LOW                                                               | LOW                                                                | STANDBY                                                                                                                                                              |

(1) VDD5\_CL DMUX output is valid only when VDD5\_EN bit in SENS\_CTRL register is set to 1. When VDD5\_EN is cleared to 0, this VDD5\_CL will be high.

### **5.4.5 Loss-of-Clock Monitor (LCMON)**

The LCMON detects internal oscillator failures including:

- Oscillator clock stuck high or stuck low
- Reduced clock frequency

The LCMON is enabled during a power-up event after the power-on reset (NPOR) is released. The clock monitor remains active during device normal operation (STANDBY, RESET, DIAGNOSTIC, ACTIVE, and SAFE states). In case of a clock failure:

- The device transitions to the STANDBY state.
- All regulators are disabled.
- The digital core is reinitialized.
- The reset to the external MCU is asserted low.
- The failure condition is indicated by the LOCLK bit in the SAFETY\_STAT\_4 register.

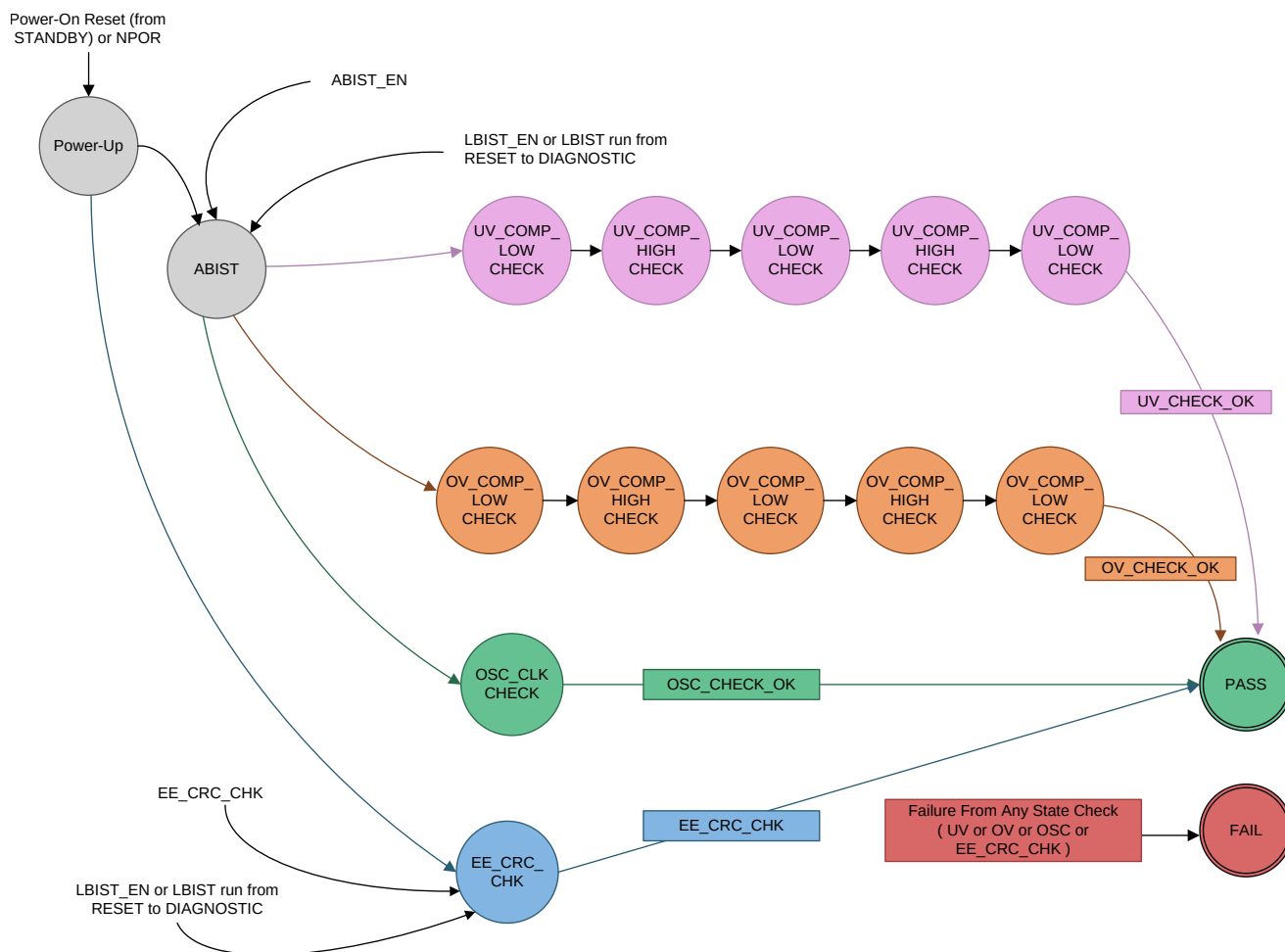
The LCMON has a self-test structure that is activated and monitored by an analog BIST (ABIST). The external MCU can recheck the LCMON any time when the device is in the DIAGNOSTIC state or ACTIVE state. The enabled diagnostics emulate a clock failure that causes the clock-monitor output to toggle. The clock-monitor toggling pattern is checked by the ABIST, while the external MCU can check that the loss-of-clock status bit is being set during active test. During this self-test, the actual oscillator frequency (4 MHz) is not changed because of this self-test.

### **5.4.6 Analog Built-In Self-Test (ABIST)**

The ABIST is the controller and monitor circuit for performing self-checking diagnostics on critical analog functions:

- VMON undervoltage and overvoltage comparators
- Clock monitor (LCMON)
- EEPROM analog-trim content check (CRC protection)

During the self-test on the VMON undervoltage and overvoltage comparators, the monitored voltage rails are left unchanged, so no real undervoltage or overvoltage event occurs on any of these rails because of these self-tests. Furthermore, also during the self-check on the clock monitor, the actual oscillator frequency (4 MHz) is not changed because of this self-test.



- (1) For impact to the device state if any ABIST function has a FAIL, see [Section 5.4.19](#).

**Figure 5-3. Analog BIST Run States**

The ABIST is activated with every device power-up event or any transition to the RESET state. The ABIST can also be run by the external MCU by setting the ABIST\_EN bit in the SAFETY\_BIST\_CTRL register. During an ABIST run, the device cannot monitor the state of the regulated supplies, and the ENDRV pin is pulled low. The ABIST run time is approximately 300  $\mu$ s. The ABIST can be performed in the ACTIVE state on an MCU request, depending on system safety requirements (such as a system-fault response time), ENDRV pin will be low during ABIST run.

A running ABIST is indicated in the ABIST\_RUN bit (bit D0) in the SAFETY\_STAT\_3 register. This bit is set to 1 during the ABIST run and is cleared to 0 when the ABIST is complete. In case of an ABIST failure while in the DIAGNOSTIC state, including power-up event, the device enters the SAFE state without asserting a reset to the external MCU and the ABIST\_ERR status flag remains latched in the digital core until a successful ABIST run. This allows the external MCU to detect the ABIST failure by reading the ABIST\_ERR bits in the SAFETY\_STAT\_3 register. In case of an ABIST failure while in the ACTIVE state, the device sets the ABIST\_ERR status flag, but no state transition occurs.

### 5.4.7 Logic Built-In Self-Test (LBIST)

The logic BIST (LBIST) tests the digital-core safety functions. The LBIST has these characteristics:

- An application-controllable logic BIST engine, which applies test vectors to the digital core.
- The LBIST engine provides stuck-at fault test coverage to logic blocks under test.
- The LBIST run time is typically 4.2 ms ( $\pm 5\%$ ). After the LBIST, a 16-ms (typical) wait period occurs to fill the digital filters covered by the LBIST. During this time, the ABIST runs. The total BIST time is approximately 21 ms. The SPI registers may be unavailable during a BIST, so no SPI reads or writes should be made while the BIST is running.
- The LBIST engine has a time-out counter as a fail-safe feature.

The BIST (LBIST with ABIST) is activated and run in the DIAGNOSTIC state with any transition out of the RESET state during power-up events. The BIST is also activated with any other transition out of the RESET state unless the AUTO\_BIST\_DIS bit in the SAFETY\_BIST\_CTRL register is set.

The MCU can run the LBIST (BIST) by setting the LBIST\_EN bit in the SAFETY\_BIST\_CTRL register.

#### NOTE

In the ACTIVE state the following considerations must be considered if a manual run of the LBIST is initiated by setting the LBIST\_EN bit to 1. The LBIST should only be run in the ACTIVE state if the system-safety timing requirements can allow the total 21-ms BIST time and ENDRV being low for the 21-ms time.

#### NOTE

In the ACTIVE or DIAGNOSTIC or SAFE state the following considerations must be considered if a manual run of the LBIST is initiated by setting the LBIST\_EN bit to 1. After the LBIST is complete the WD\_FAIL\_CNT[2:0] counter is re-initialized to 5. The MCU should resynchronize to the TPS65381A-Q1 watchdog by writing to the WD\_WIN1\_CFG or WD\_WIN2\_CFG register or by immediately causing a bad event. Both of these resynchronization options start a new watchdog sequence and increment the WD\_FAIL\_CNT[2:0] counter. If the WD\_RST\_EN bit is set to 1 (enabled), the watchdog service routine in the MCU must ensure good events are sent to the watchdog to start decrementing the WD\_FAIL\_CNT[2:0] counter before it reaches 7 +1 which cause a transition to the RESET state. After the LBIST is complete some of the registers are reinitialized. If the these configuration registers change from the initialized values, these registers must be reconfigured to the required setting for the application.

#### NOTE

In the DIAGNOSTIC state the following considerations must be taken into account if a manual run of the LBIST is initiated by setting the LBIST\_EN bit to 1. Setting the LBIST\_EN bit to 1 clears the DIAG\_EXIT\_MASK bit to 0. If the DIAG\_EXIT\_MASK bit is being used to hold the device in the DIAGNOSTIC state for software debug, it must be set again to 1 after LBIST completion to stay in the DIAGNOSTIC state. The DIAGNOSTIC state time-out counter stops only during the running of the LBIST. After the LBIST is complete, the time-out counter continues from the last value. For a transition from the DIAGNOSTIC state to the ACTIVE state, the DIAG\_EXIT bit must be set to 1.

During the BIST run, the device cannot monitor the state of regulated supplies and cannot respond to any SPI command, and therefore cannot monitor the state of the MCU through the watchdog timer. During the BIST run, the ENDRV pin is pulled low and the watchdog fail counter reinitializes to 5. After the BIST is complete, the following functions and registers reinitialize:

- DEV\_STAT
- SAFETY\_STAT\_2
- SAFETY\_STAT\_4
- SAFETY\_STAT\_5 (but FSM[2:0] will immediately update to reflect the current device state)
- WD\_TOKEN\_VALUE
- WD\_STATUS
- SAFETY\_CHECK\_CTRL
- DIAG\_CFG\_CTRL
- DIAG\_MUX\_SEL

A running LBIST is indicated in the LBIST\_RUN bit (bit D1) in the SAFETY\_STAT\_3 register. This bit is set to 1 while the LBIST is running and is cleared to 0 when the LBIST is complete. After the LBIST run, completion of the whole BIST is confirmed by the MCU by reading 0 for both the LBIST\_RUN and ABIST\_RUN bits.

In case of an LBIST failure in the DIAGNOSTIC state, the device enters the SAFE state. The external MCU can detect the LBIST failure by reading the LBIST\_ERR bit in the SAFETY\_STAT\_3 register. In case of an LBIST failure while in the ACTIVE state, the device sets the LBIST\_ERR status flag, but no state transition occurs. Because the ABIST is run during the LBIST, the ABIST\_ERR bit can also be monitored by the MCU.

#### 5.4.8 Junction Temperature Monitoring and Current Limiting

Each LDO with an internal power FET has junction temperature monitoring with overtemperature protection (thermal shutdown). In case of an overtemperature condition, a regulated supply can re-enable only after the overtemperature condition is removed.

For the VSOUT1 regulator, the overtemperature condition disables the regulator and clears the enable bit (VSOUT1\_EN), while all other regulators remain enabled. When the VSOUT1 overtemperature condition is gone, the external MCU must set the enable control bit again to re-enable the regulator.

The VDD3/5 and VDD6 regulators share an overtemperature protection circuit. A overtemperature event disables the VDD3/5 regulator. If the NMASK\_VDD3/5\_OT is set to 1 (default), the device transitions to the STANDBY state. If the NMASK\_VDD3/5\_OT bit is cleared to 0, the device transitions to the RESET state when the VDD3/5 output reaches the UV level for the VDD3/5 regulator. In both cases the NRES pin goes low and resets the external MCU and the ENDRV pin is low. TI recommends using the device with the NMASK\_VDD3/5\_OT bit set to 1.

For the VDD5 regulator, the overtemperature condition clears the VDD5\_EN enable bit and transitions to the RESET state. NRES pin goes low and resets the MCU and the ENDRV pin is low. All other regulators remain enabled. When the VDD5 overtemperature condition is gone, the MCU must set the enable control bit again to re-enable the regulator.

The VDD6, VDD3/5, VDD5, and VSOUT1 regulators include a current-limit circuit for protection against excessive power consumption and thermal overstress.



Table 5-3 lists an overview of the overtemperature and overcurrent protections for the supply output rails.

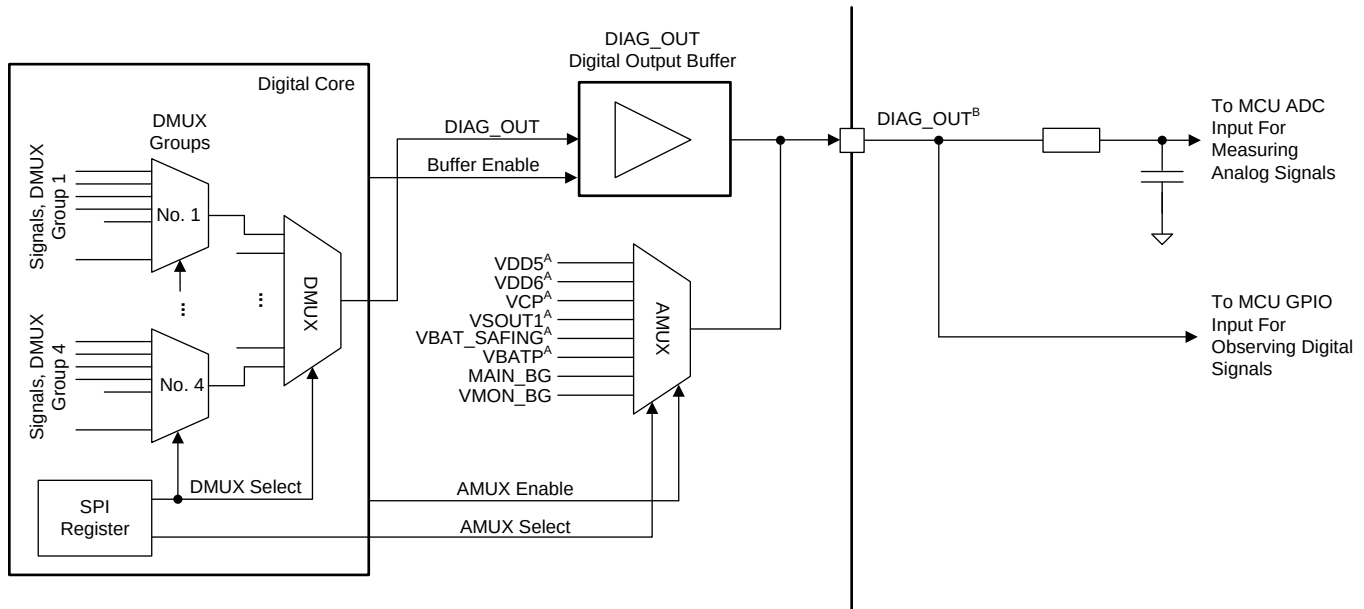
**Table 5-3. Overtemperature and Overcurrent Protection Overview**

| VOLTAGE<br>RAIL | OVERTEMPERATURE PROTECTION                  |                                                                                                                                                                                                               | OVERCURRENT PROTECTION |                                               |
|-----------------|---------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|-----------------------------------------------|
|                 | THRESHOLD (°C)                              | IMPACT ON DEVICE<br>BEHAVIOR                                                                                                                                                                                  | CURRENT-LIMIT          | IMPACT ON DEVICE BEHAVIOR                     |
| VDD6            | 175 to 210 (shared with<br>VDD6 and VDD3/5) | Sets VDD3/5_OT (in<br>SAFETY_STAT_1)<br>when NMASK_VDD3/5_OT =<br>1, STANDBY state<br>when NMASK_VDD3/5_OT =<br>0, disables VDD3/5, RESET<br>when VDD3/5 reaches UV<br>level                                  | 1.5 to 2.5 A           | None                                          |
| VDD3/5          |                                             |                                                                                                                                                                                                               | 350 to 650 mA          | Sets VDD3/5_ILIM (in<br>SAFETY_STAT_1)        |
| VDD5            | 175 to 210                                  | Sets VDD5_OT (in<br>SAFETY_STAT_1)<br>when NMASK_VDD5_OT = 1,<br>clears VDD5_EN (in<br>SENS_CTRL) and VDD5<br>switched off, RESET state<br>when NMASK_VDD5_OT = 0,<br>overtemperature indicated in<br>VDD5_OT | 350 to 650 mA          | Sets VDD5_ILIM (in<br>SAFETY_STAT_1)          |
| VDD1            | None                                        | N/A                                                                                                                                                                                                           | None                   | N/A                                           |
| VSOUT1          | 175 to 210                                  | Sets VSOUT1_OT (in<br>SAFETY_STAT_1)<br>clears VSOUT1_EN (in<br>SENS_CTRL) and VSOUT1<br>disabled                                                                                                             | 100 to 500 mA          | DIAG_OUT through digital MUX<br>for VSOUT1_CL |

### 5.4.9 Diagnostic MUX and Diagnostic Output Pin (DIAG\_OUT)

Analog and digital critical signals, which are not directly connected to the MCU, are switched by a multiplexer to the external DIAG\_OUT pin. The programming of the multiplexer is done with the DIAG\_MUX\_SEL register. The digital signals are buffered to have sufficient drive capabilities.

This multiplexer facilitates external pin-interconnect tests by feeding back the input pin state or feeding back internal module self-test status or safety comparator outputs.



- A. These analog signals are multiplexed out with a divide ratio
- B. If the application must measure analog signals with an MCU ADC and monitor digital signals with an MCU GPIO, the application design must assure the GPIO input stage does not affect the ADC measurements. If isolating the MCU GPIO is not possible within the MCU, the application design must achieve the necessary isolation externally.

**Figure 5-4. Diagnostic Output Pin, DIAG\_OUT**

In case the DIAG\_OUT pin is connected to a mixed analog or digital input pin of the MCU, TI recommends configuring this MCU input pin and the DIAG\_OUT pin simultaneously in accordance with the desired type of signal (analog or digital). The type of signal (analog or digital) on the DIAG\_OUT pin can be configured with the MUX\_CFG[1:0] bits in the DIAG\_CFG\_CTRL register. The DIAG\_OUT multiplexer can be globally enabled and disabled with bit 7 in the DIAG\_CFG\_CTRL register. When disabled, the DIAG\_OUT pin is in the high-ohmic state (tri-state).

#### NOTE

When enabling the DIAG\_OUT MUX while using SPI communication, the SDO pin is not in the high impedance state while the NCS pin is high and the DIAG\_OUT MUX is enabled. Software or hardware modification may be required in the application. For hardware modifications check the SDO threshold level and drive capability if resistors are used to adjust the voltage level of the SDO pin on the SPI bus or use a buffer gate with an enable and tri-state output such as the [SN74AHC1G125](#) to allow the downstream SDO signal to be in the high impedance state if required in the application while the NCS pin is high even if the DIAG\_OUT MUX is enabled.

### 5.4.9.1 Analog MUX (AMUX)

Table 5-4 lists the selectable-analog internal signals on the DIAG\_OUT pin. In the DIAG\_CFG\_CTRL register, the MUX\_CFG[1:0] bits must be set to 10b for the analog MUX mode.

**Table 5-4. Analog MUX Selection Table**

| SIGNAL NUMBER | VOLTAGE RAIL or SIGNAL NAME | DESCRIPTION                                                    | SUPPLY RANGE <sup>(1)</sup> | DIVIDE RATIO | DIVIDE RATIO ACCURACY <sup>(2)</sup> |         | OUTPUT RESISTANCE (kΩ) |         | DIAG_MUX_SEL[7:0] |
|---------------|-----------------------------|----------------------------------------------------------------|-----------------------------|--------------|--------------------------------------|---------|------------------------|---------|-------------------|
|               |                             |                                                                |                             |              | MINIMUM                              | MAXIMUM | MINIMUM                | MAXIMUM |                   |
| A.1           | VDD5                        | Linear VDD5 regulator output                                   | 5.8 to 34 V                 | 2            | –2.25 %                              | 0.75 %  | 20                     | 50      | 0x01              |
| A.2           | VDD6                        | Switch mode preregulator                                       | 5.8 to 34 V                 | 3            | –3.75%                               | 0.5 %   | 30                     | 100     | 0x02              |
| A.3           | VCP                         | Charge pump                                                    | 5.8 to 18V                  | 13.5         | –6.25 %                              | 2.25 %  | 90                     | 200     | 0x04              |
|               |                             |                                                                | 5.8 to 34 V                 |              | –6.25%                               | 4.75 %  |                        |         |                   |
| A.4           | VSOUT1                      | Sensor supply voltage                                          | 5.8 to 34 V                 | 4            | –0.5 %                               | 1.2 %   | 40                     | 100     | 0x08              |
| A.5           | VBAT_SAFING                 | Battery (supply) input for monitoring (VMON) and BG2 functions | 5.8 to 18 V                 | 10           | –5 %                                 | 0 %     | 125                    | 200     | 0x10              |
|               |                             |                                                                | 5.8 to 34 V                 |              | –5 %                                 | 5.5 %   |                        |         |                   |
| A.6           | VBATP                       | Battery (supply), main power supply                            | 5.8 to 18V                  | 10           | –5 %                                 | 0 %     | 125                    | 200     | 0x20              |
|               |                             |                                                                | 5.8 to 34 V                 |              | –5 %                                 | 5.5 %   |                        |         |                   |
| A.7           | MAIN_BG                     | Regulators band-gap reference                                  | 5.8 to 34 V                 | 1            | NA                                   |         | 3                      | 15      | 0x40              |
| A.8           | VMON_BG                     | Voltage-monitor band gap                                       | 5.8 to 34 V                 | 1            | NA                                   |         | 3                      | 15      | 0x80              |

(1) The supply range is the input supply range for VBATP and VBAT\_SAFING (VBATP = VBAT\_SAFING).

(2) The given accuracies are without the DC load-current drawn from the DIAG\_OUT pin. For overall accuracy calculation, the divide ratio accuracy and the drop voltage caused by  $I_{\text{DIAG\_OUT}} \times \text{output resistance}$  must be considered.

In case one of the AMUX signals after the divide ratio is at a voltage above the VDDIO voltage, a clamp becomes active to avoid any voltage level higher than the VDDIO voltage on the DIAG\_OUT pin.

To achieve the fastest stabilization of the signal switched to the DIAG\_OUT pin, following the AMUX switching order from A.1 up to A.8 is not recommended.

The recommendation is to switch the order from high-to-low voltage, starting with A.8. For example: A.8 – A.7 – A.1 – A.2 – A.3 – A.5 – A.6 – A.4.

#### NOTE

The sensor-supply output voltage (VSOUT1) is 0 V in this example. If the VSOUT1 voltage is higher, then the switching order described in the previous example must be changed.

#### NOTE

In the application, a series resistance of at least 100 kΩ is required on the input capacitor filter of the ADC input of the MCU.

### 5.4.9.2 Digital MUX (DMUX)

The following tables list the selectable digital internal signals on the DIAG\_OUT pin. In the DIAG\_CFG\_CTRL register, the MUX\_CFG[1:0] bits must be cleared to 01b for the digital MUX mode.

Most of these signals are internal error signals that influence the device state and behavior of the NRES pin and the ENDRV pin. See Table 5-2 for a more detailed table listing the internal error signals and their impact on the device behavior.

**Table 5-5. Digital MUX Selection Table – Group 1**

| SIGNAL NUMBER | SIGNAL NAME | DESCRIPTION                                          | CHANNEL GROUP<br>DIAG_MUX_SEL<br>[6:4] | CHANNEL<br>NUMBER<br>DIAG_MUX_SEL<br>[3:0] |
|---------------|-------------|------------------------------------------------------|----------------------------------------|--------------------------------------------|
| D1.1          | RSV         | Reserved, logic 0                                    | 000b                                   | 0000b                                      |
| D1.2          | NAVDD_UV    | AVDD undervoltage comparator output (inverted)       | 000b                                   | 0001b                                      |
| D1.3          | BG_ERR1     | VMON or main band gap is OFF                         | 000b                                   | 0010b                                      |
| D1.4          | BG_ERR2     | VMON or main band gap is OFF                         | 000b                                   | 0011b                                      |
| D1.5          | NVCP12_UV   | VCP12 charge-pump undervoltage comparator (inverted) | 000b                                   | 0100b                                      |
| D1.6          | VCP12_OV    | VCP12 charge-pump overvoltage comparator             | 000b                                   | 0101b                                      |
| D1.7          | VCP17_OV    | VCP17 charge-pump overvoltage comparator             | 000b                                   | 0110b                                      |
| D1.8          | NVDD6_UV    | VDD6 undervoltage comparator (inverted)              | 000b                                   | 0111b                                      |
| D1.9          | VDD6_OV     | VDD6 overvoltage comparator                          | 000b                                   | 1000b                                      |
| D1.10         | NVDD5_UV    | VDD5 undervoltage comparator (inverted)              | 000b                                   | 1001b                                      |
| D1.11         | VDD5_OV     | VDD5 overvoltage comparator                          | 000b                                   | 1010b                                      |
| D1.12         | NVDD3/5_UV  | VDD3/5 undervoltage comparator (inverted)            | 000b                                   | 1011b                                      |
| D1.13         | VDD3/5_OV   | VDD3/5 overvoltage comparator                        | 000b                                   | 1100b                                      |
| D1.14         | NVDD1_UV    | VDD1 undervoltage comparator (inverted)              | 000b                                   | 1101b                                      |
| D1.15         | VDD1_OV     | VDD1 overvoltage comparator                          | 000b                                   | 1110b                                      |
| D1.16         | LOCLK       | Loss-of-system-clock comparator                      | 000b                                   | 1111b                                      |

**Table 5-6. Digital MUX Selection Table – Group 2**

| SIGNAL NUMBER | SIGNAL NAME  | DESCRIPTION                                    | CHANNEL GROUP<br>DIAG_MUX_SEL<br>[6:4] | CHANNEL<br>NUMBER<br>DIAG_MUX_SEL<br>[3:0] |
|---------------|--------------|------------------------------------------------|----------------------------------------|--------------------------------------------|
| D2.1          | RSV          | Reserved, logic 0                              | 001b                                   | 0000b                                      |
| D2.2          | SYS_CLK      | System clock source                            | 001b                                   | 0001b                                      |
| D2.3          | DFT          | Signal reserved for production test            | 001b                                   | 0010b                                      |
| D2.4          | WD_CLK       | Watchdog clock reference (0.55-ms period time) | 001b                                   | 0011b                                      |
| D2.5          | RST_EXT_CLK  | Reset extension oscillator output              | 001b                                   | 0100b                                      |
| D2.6          | T_5US        | 5-μs time reference                            | 001b                                   | 0101b                                      |
| D2.7          | T_15US       | 15-μs time reference                           | 001b                                   | 0110b                                      |
| D2.8          | T_40US       | 40-μs time reference                           | 001b                                   | 0111b                                      |
| D2.9          | T_2MS        | 2-ms time reference                            | 001b                                   | 1000b                                      |
| D2.10         | UC_ERROR/WDI | External MCU ERROR/WDI input pin               | 001b                                   | 1001b                                      |
| D2.11         | SPI_NCS      | SPI chip-select input pin                      | 001b                                   | 1010b                                      |
| D2.12         | SPI_SDI      | SPI slave-data input pin                       | 001b                                   | 1011b                                      |
| D2.13         | SPI_CLK      | SPI clock input pin                            | 001b                                   | 1100b                                      |
| D2.14         | SDO_RDBCK    | SPI slave-data output-pin readback             | 001b                                   | 1101b                                      |
| D2.15         | UC_ERROR/WDI | Same signal as D2.10                           | 001b                                   | 1110b                                      |
| D2.16         | NRES_EXT_IN  | NRES pin readback (reset to external MCU)      | 001b                                   | 1111b                                      |

**Table 5-7. Digital MUX Selection Table – Group 3**

| SIGNAL NUMBER | SIGNAL NAME | DESCRIPTION                                    | CHANNEL GROUP<br>DIAG_MUX_SEL<br>[6:4] | CHANNEL NUMBER<br>DIAG_MUX_SEL<br>[3:0] |
|---------------|-------------|------------------------------------------------|----------------------------------------|-----------------------------------------|
| D3.1          | RSV         | Reserved, logic 0                              | 010b                                   | 0000b                                   |
| D3.2          | DFT         | Signal reserved for production test            | 010b                                   | 0001b                                   |
| D3.3          | DFT         | Signal reserved for production test            | 010b                                   | 0010b                                   |
| D3.4          | CP_OV       | Charge-pump overvoltage comparator             | 010b                                   | 0011b                                   |
| D3.5          | NCP_UV      | Charge-pump undervoltage comparator (inverted) | 010b                                   | 0100b                                   |
| D3.6          | CP_PH1      | Charge-pump switching phase 1                  | 010b                                   | 0101b                                   |
| D3.7          | CP_PH2      | Charge-pump switching phase 2                  | 010b                                   | 0110b                                   |
| D3.8          | CP_DIFF3V   | Indicates VCP-VBATP > 3 V                      | 010b                                   | 0111b                                   |
| D3.9          | DFT         | Signal reserved for production test            | 010b                                   | 1000b                                   |
| D3.10         | NVBAT_UV    | VBAT undervoltage comparator (inverted)        | 010b                                   | 1001b                                   |
| D3.11         | VBATP_OV    | VBAT overvoltage comparator                    | 010b                                   | 1010b                                   |
| D3.12         | VDD5_OT     | VDD5 overtemperature                           | 010b                                   | 1011b                                   |
| D3.13         | VDD3/5_OT   | VDD3/5 overtemperature                         | 010b                                   | 1100b                                   |
| D3.14         | VSOUT1_OT   | VSOUT1 overtemperature                         | 010b                                   | 1101b                                   |
| D3.15         | VDD5_CL     | VDD5 current-limit                             | 010b                                   | 1110b                                   |
| D3.16         | VDD3_CL     | VDD3 current-limit                             | 010b                                   | 1111b                                   |

**Table 5-8. Digital MUX Selection Table – Group 4**

| SIGNAL NUMBER | SIGNAL NAME   | DESCRIPTION                               | CHANNEL GROUP<br>DIAG_MUX_SEL<br>[6:4] | CHANNEL NUMBER<br>DIAG_MUX_SEL<br>[3:0] |
|---------------|---------------|-------------------------------------------|----------------------------------------|-----------------------------------------|
| D4.1          | RSV           | Reserved, logic 0                         | 011b                                   | 0000b                                   |
| D4.2          | VSOUT1_CL     | VSOUT1 current-limit                      | 011b                                   | 0001b                                   |
| D4.3          | NVSOUT1_UV    | VSOUT1 undervoltage comparator (inverted) | 011b                                   | 0010b                                   |
| D4.4          | VSOUT1_OV     | VSOUT1 overvoltage comparator             | 011b                                   | 0011b                                   |
| D4.5          | NDVDD_UV      | DVDD undervoltage comparator (inverted)   | 011b                                   | 0100b                                   |
| D4.6          | DVDD_OV       | DVDD overvoltage comparator               | 011b                                   | 0101b                                   |
| D4.7          | RSV           | Reserved                                  | 011b                                   | 0110b                                   |
| D4.8          | VS_TRK_MODE   | VSOUT1 in track-mode indication           | 011b                                   | 0111b                                   |
| D4.9          | VMON_TRIM_ERR | VMON trim error                           | 011b                                   | 1000b                                   |
| D4.10-16      | RSV           | Reserved                                  | 011b                                   | 1001b-1111b                             |

**Table 5-9. Digital MUX Selection Table – Group 5**

| SIGNAL NUMBER | SIGNAL NAME  | DESCRIPTION                         | CHANNEL GROUP<br>DIAG_MUX_SEL<br>[6:4] | CHANNEL NUMBER<br>DIAG_MUX_SEL<br>[3:0] |
|---------------|--------------|-------------------------------------|----------------------------------------|-----------------------------------------|
| D5.1          | RSV          | Reserved, logic 0                   | 111b                                   | 0000b                                   |
| D5.2          | TI_TEST_MODE | TI production test mode indication  | 111b                                   | 0001b                                   |
| D5.3-16       | DFT          | Signal reserved for production test | 111b                                   | 0010b-1111b                             |

A diagnostic check at the SDO digital-output pin is also possible in DMUX mode. For this diagnostic check, the following sequence is required:

1. The MUX\_CFG[1:0] configuration must be set to 01b for DIGITAL MUX mode.
2. The SPI NCS must be kept HIGH.
3. The state of the SDO pin is controlled by the SPI\_SDO bit (bit D6 in the DIAG\_CFG\_CTRL register).

During this SDO check at the SDO pin, the DIAG\_OUT pin is kept low if no signal from the Digital MUX Selection table is selected.

#### 5.4.9.3 Diagnostic MUX Output State (by MUX\_OUT bit)

For a diagnostic interconnect check between the DIAG\_OUT pin and the MCU analog-digital input pin, the state of the DIAG\_OUT pin is controlled with the SPI bit, MUX\_OUT, in the DIAG\_CFG\_CTRL register. To use this mode, the MUX\_CFG[1:0] bits must be set to 00b in the DIAG\_CFG\_CTRL register.

#### 5.4.9.4 MUX Interconnect Check

For performing a diagnostic interconnect check at the digital input pins (ERROR/WDI, NCS, SDI, and SCLK), the MUX\_CFG[1:0] bits in the DIAG\_CFG\_CTRL register must be set to 11b. The INT\_CON[2:0] bits in the DIAG\_CFG\_CTRL register can select which of these digital inputs to be multiplexed to the DIAG\_OUT pin (see the description of DIAG\_CFG\_CTRL register in [Section 5.5.1](#)).

#### 5.4.10 Watchdog Timer (WD)

The watchdog monitors the correct operation of the MCU. This watchdog requires specific triggers, or messages, from the MCU in specific time intervals to detect correct operation of the MCU. The MCU can control the logic level of the ENDRV pin with the ENABLE\_DRV bit when the watchdog detects correct operation of the MCU. When the watchdog detects incorrect operation of the MCU, the device pulls the ENDRV pin low. This ENDRV pin can be used in the application as a control signal to deactivate the power output stages, for example a motor driver, in case of incorrect operation of the MCU. This function is consequently referred to as the watchdog-enabled function.

The watchdog has two different modes, which are defined as follows:

**Trigger mode:** In trigger mode, the MCU applies a trigger (pulse) on the ERROR/WDI pin to send the required watchdog event for trigger mode. The watchdog operates in trigger mode as the default mode when the device goes from the RESET state to the DIAGNOSTIC state. The MCU error signal monitor (ESM) should not be used when the watchdog operates in trigger mode.

**Question-answer mode (Q&A mode):** In Q&A mode, the MCU sends watchdog answers through SPI.

To select the Q&A mode, the MCU must set the WD\_CFG bit (bit 5) in the safety-function configuration register (SAFETY\_FUNC\_CFG) while in the DIAGNOSTIC state. When the watchdog operates in Q&A mode, the MCU error signal monitor (ESM) may be used.

#### 5.4.11 Watchdog Fail Counter, Status, and Fail Event

The watchdog includes a watchdog fail counter (WD\_FAIL\_CNT[2:0]) which increments because of *bad events* or decrements because of *good events*. When the value of the watchdog fail counter is 5 or more, the watchdog status is out-of-range and the ENDRV pin is low (the watchdog-enabled function is disabled).

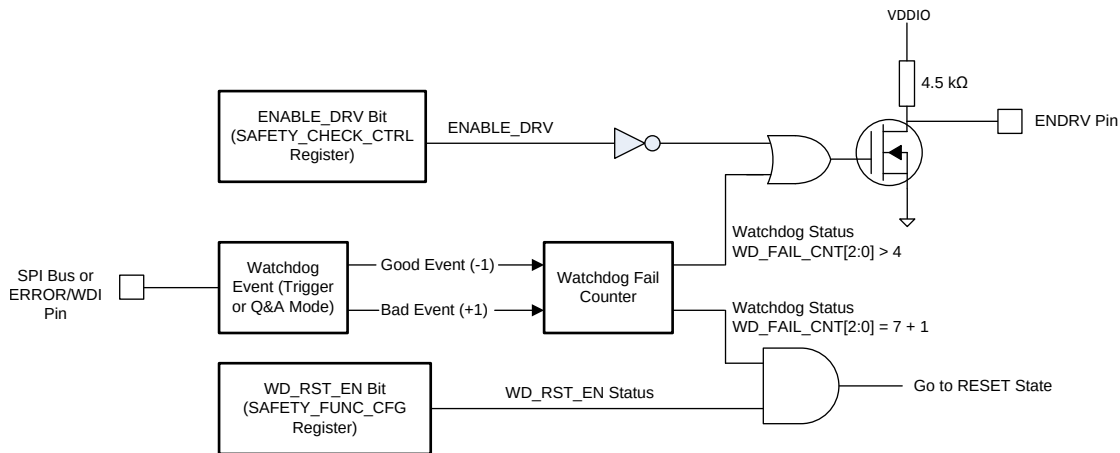
When the watchdog fail counter is 4 or less, the watchdog status is in-range and the watchdog no longer disables the watchdog-enabled function. In this case, the device pulls up the ENDRV pin when the ENABLE\_DRV control bit (in the SAFETY\_CHECK\_CTRL register) is set and when the device detects no other errors that impact the level of the ENDRV pin.

The watchdog fail counter operates independently of the state of the watchdog reset configuration bit (bit 3), WD\_RST\_EN, in the SAFETY\_FUNC\_CFG register.

The watchdog fail counter responds as follows:

- A *good event* decrements the fail counter by one, down to the minimum of zero.
- A *bad event* increments the fail counter by one, up to the maximum of seven.
- A *time-out event* increases the fail counter by one, up to the maximum of seven, and sets the TIME\_OUT flag (WD\_STATUS register, bit 1).

The definitions of *good event*, *bad event* and *time-out event* are listed [Section 5.4.14](#) and [Section 5.4.15](#).



**Figure 5-5. Watchdog Impact on ENDRV and RESET**

**Table 5-10. Watchdog Status for Range of the Watchdog Fail Counter Value**

| WATCHDOG FAIL COUNTER<br>WD_FAIL_CNT[2:0]                   | 000b THROUGH 100b | 101b THROUGH 111b        | 111b                                                                                                                                             |
|-------------------------------------------------------------|-------------------|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| The watchdog status is based on the WD_FAIL_CNT[2:0] value. | Watchdog in-range | Watchdog is out-of-range | If the WD_RST_EN bit is set to 1, the NRES pin is pulled low, the device is in the RESET state on next "bad" or "time-out" event to the watchdog |

The watchdog fail counter is initialized to a count of 5 when the device enters the DIAGNOSTIC state (after going through the RESET state) and when the device transitions from the DIAGNOSTIC state to the ACTIVE state.

When the watchdog fail counter reaches a count of 7, another *bad event* does not change the counter: the counter remains at 7. However, if the watchdog reset is enabled (WD\_RST\_EN bit in the SAFETY\_FUNC\_CFG register is set to 1), on the next *bad event* or *time-out event* (7 + 1) the device enters the RESET state and resets the MCU by pulling the NRES pin low. In the RESET state, the watchdog fail counter reinitializes to 5. If the watchdog fail counter is at seven when the WD\_RST\_EN bit is set to 1, the device immediately enters the RESET state without requiring another *bad event* or *time-out event*.

### 5.4.12 Watchdog Sequence

Each watchdog sequence begins with a Window 1 followed by a Window 2. The MCU can program the time periods of Window 1 ( $t_{WIN1}$ ) and Window 2 ( $t_{WIN2}$ ) with the WD\_WIN1\_CFG and WD\_WIN2\_CFG registers respectively when the device is in the DIAGNOSTIC state. When the device goes from the RESET state to the DIAGNOSTIC state, the watchdog sequence begins with the default  $t_{WIN1}$  and  $t_{WIN2}$  time periods.

Use Equation 1 and Equation 2 to calculate the minimum and maximum values for the  $t_{WIN1}$  time period. Use Equation 3 and Equation 4 to calculate the minimum and maximum values for the  $t_{WIN2}$  time period.

$$t_{WIN1\_MIN} = [(RT[6:0] - 1) \times 0.55 \times 0.95] \text{ ms}$$

where

- The bits RT[6:0] are located in the WD\_WIN1\_CFG SPI register.

(1)

$$t_{WIN1\_MAX} = (RT[6:0] \times 0.55 \times 1.05) \text{ ms}$$

where

- The bits RT[6:0] are located in the WD\_WIN1\_CFG SPI register.

(2)

$$t_{WIN2\_MIN} = [(RW[4:0] + 1) \times 0.55 \times 0.95] \text{ ms}$$

where

- The bits RW[4:0] are located in the WD\_WIN2\_CFG SPI register.

(3)

$$t_{WIN2\_MAX} = [(RW[4:0] + 1) \times 0.55 \times 1.05] \text{ ms}$$

where

- The bits RW[4:0] are located in the WD\_WIN2\_CFG SPI register.

(4)

If the MCU stops sending *events*, or stops *feeding the watchdog* during the watchdog sequence, the watchdog considers this lack of response from the MCU a *time-out event (no response event)*. This sets the TIME\_OUT status bit (bit 1 in the WD\_STATUS register) and increments the watchdog fail counter. Immediately following a *time-out event* the next watchdog sequence is started.

Based on the Window 1 and Window 2 time periods, the watchdog sequence and time-out time periods are calculated as follows:

$$t_{SEQUENCE\_MIN} = t_{TIMEOUT\_MIN} = t_{WIN1\_MIN} + t_{WIN2\_MIN} \quad (5)$$

$$t_{SEQUENCE\_MAX} = t_{TIMEOUT\_MAX} = t_{WIN1\_MAX} + t_{WIN2\_MAX} \quad (6)$$

The watchdog uses the internal system clock of the device ( $\pm 5\%$  accuracy) as a time reference for creating the 0.55-ms watchdog time step. WINDOW 1 may be up to one 0.55-ms watchdog time step shorter than programmed as indicated by Equation 1.

#### NOTE

Because of the uncertainty in the Window 1 and Window 2 time periods, TI recommends using settings for Window 1 and Window 2 of two or higher. Window 2 could be set as low as one, assuming Window 1 is set to six or lower. The response from the MCU should be targeted to the mid point of known timing for Window 2. As Window 1 setting is increased above six, the device system-clock tolerance ( $\pm 5\%$ ) becomes large compared to a setting of one in Window 2 not allowing for a known time range for a response in Window 2, so Window 2 setting must be scaled with Window 1 to allow timing margin.



### 5.4.13 MCU to Watchdog Synchronization

To synchronize the MCU with the watchdog sequence, the MCU can write to either the WIN1\_CFG or WIN2\_CFG registers to start a new watchdog sequence. After a write access to the WIN1\_CFG or WIN2\_CFG register by the MCU (even when these registers are locked or when the device is in the ACTIVE or the SAFE state), the device immediately starts a new watchdog sequence and increments the watchdog fail counter. Therefore a write access to the WD\_WIN1\_CFG or WD\_WIN2\_CFG register only takes effect in this new watchdog sequence.

When the MCU is synchronized with the watchdog sequence, a *good event* from the MCU immediately starts a new watchdog sequence. In this way, the MCU stays synchronized with the watchdog sequence.

See [Figure 6-11](#) for an example software flowchart of how to synchronize the MCU with the TPS65381A-Q1 watchdog.

### 5.4.14 Trigger Mode (Default Mode)

When the device goes from the RESET state to the DIAGNOSTIC state, the watchdog operates in trigger mode (default). The first watchdog sequence begins with the default  $t_{WIN1}$  and  $t_{WIN2}$  time periods. The watchdog receives the triggers from the MCU on the ERROR/WDI pin. A rising edge on the ERROR/WDI pin, followed by a falling edge on the ERROR/WDI pin after more than the required pulse time,  $t_{WD\_pulse(max)}$  (32  $\mu$ s), is a trigger. Even a waveform with a longer duration high than low is counted as a trigger if the rising and falling edges meet this requirement.

Window 1, called a CLOSE window, is the first window in the watchdog sequence. A trigger received in Window 1 is a *bad event* and ends Window 1, starts a new watchdog sequence and sets ANSWER\_EARLY flag.

Window 2, called an OPEN window, follows Window 1. At a minimum, Window 2 lasts until a trigger is received. At a maximum, Window 2 lasts until the programmed  $t_{WIN2}$  time. A trigger received in Window 2 (OPEN) is a *good event*. A new watchdog sequence begins immediately after the watchdog receives a trigger in Window 2.

If the MCU stops sending triggers during the watchdog sequence, the watchdog considers this lack of response from the MCU a *time-out event (no response event)*. This sets the TIME\_OUT status bit (bit 1 in the WD\_STATUS register) and increments the watchdog fail counter. Immediately following a *time-out event* a new watchdog sequence is started.

The TIME\_OUT flag can be useful for the MCU software to resynchronize the watchdog trigger pulse events to the required device watchdog timing. When resynchronizing in this way, the MCU detects the TIME\_OUT flag being set. The TIME\_OUT flag being set indicates the *time-out event* and the start of a new watchdog sequence. The MCU should send the trigger with timing so the trigger is in Window 2 (OPEN) of this new watchdog sequence.

#### NOTE

If an active SPI frame (nCS is low) is present when the *time-out event* occurs, the TIME\_OUT flag is not latched (set) in the WD\_STATUS register, but the watchdog fail counter still increments. Because the TIME\_OUT flag is not latched, this impacts the resynchronization ability of the MCU and status monitoring. It is recommended to use the synchronization procedure outlined in section [Section 5.4.13](#).

In trigger mode, the watchdog uses a deglitch filter with the  $t_{WD\_pulse}$  filter time and an internal system clock to create the internally generated watchdog pulse (see [Figure 5-6](#) and [Figure 5-7](#)).

The rising edge of the trigger on the ERROR/WDI pin must occur at least the  $t_{WD\_pulse(max)}$  time before the end of Window 2 (OPEN) to generate a good event.

The window duration times of Window 1 (CLOSE) and Window 2 (OPEN) are programmed through the WD\_WIN1\_CFG and WD\_WIN2\_CFG registers when the device is in the DIAGNOSTIC state. In trigger mode, the window duration time are as follows:

$$t_{WCW\_MIN} \text{ (Trigger mode)} = t_{WIN1\_MIN}$$

where

- WCW is a watchdog CLOSE window

(7)

$$t_{WCW\_MAX} \text{ (Trigger mode)} = t_{WIN1\_MAX}$$

where

- WCW is a watchdog CLOSE window

(8)

$$t_{WOW\_MIN} \text{ (Trigger mode)} = t_{WIN2\_MIN}$$

where

- WOW is a watchdog OPEN window

(9)

$$t_{WOW\_MIN} \text{ (Trigger mode)} = t_{WIN2\_MIN}$$

where

- WOW is a watchdog OPEN window

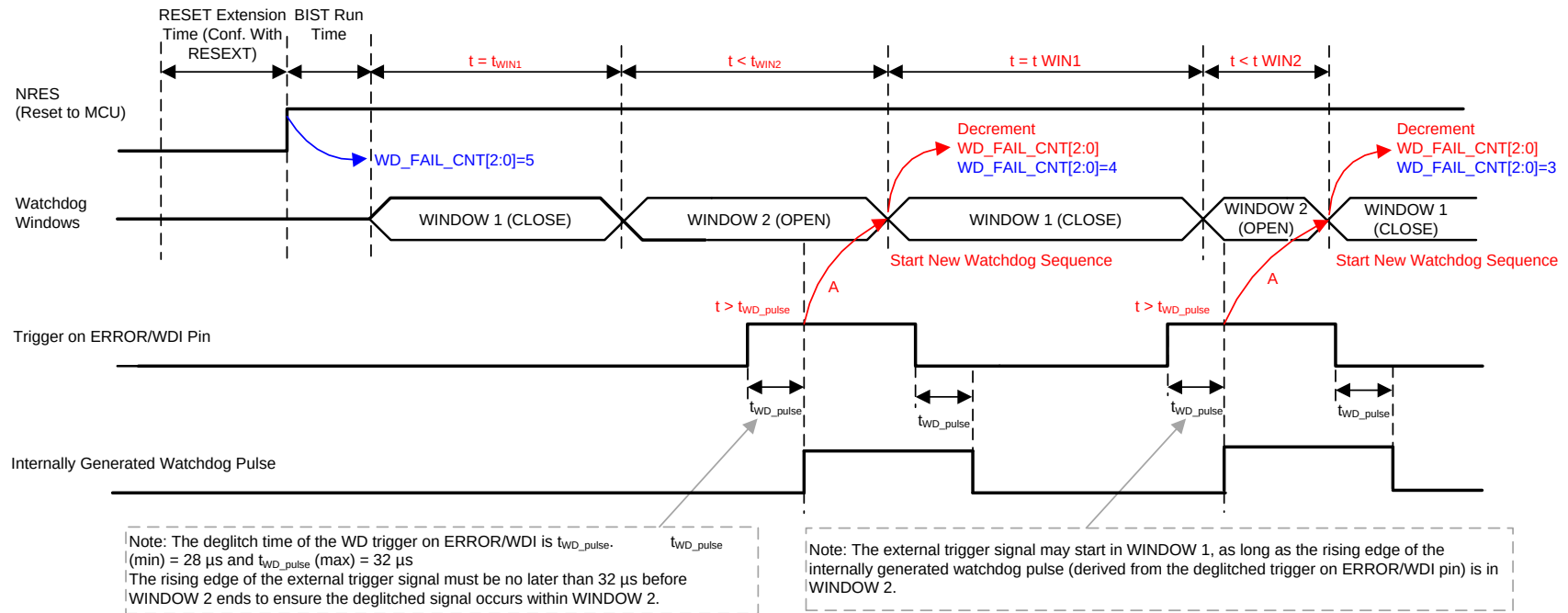
(10)

Use [Equation 1](#) and [Equation 2](#) to calculate the minimum and maximum values for the  $t_{WIN1} = t_{WCW}$  time period. Use [Equation 3](#) and [Equation 4](#) to calculate the minimum and maximum values for the  $t_{WIN2} = t_{WOW}$  time period.

Writing a new Window 1 or Window 2 time to the WD\_WIN1\_CFG or WD\_WIN2\_CFG register immediately begins a new watchdog sequence and increments the watchdog fail counter. A new watchdog sequence is started by a write even when WD\_WIN1\_CFG register and the WD\_WIN2\_CFG SPI register are locked because the device is not in DIAGNOSTIC state or the SPI command SW\_LOCK is blocking a write update to the register values.

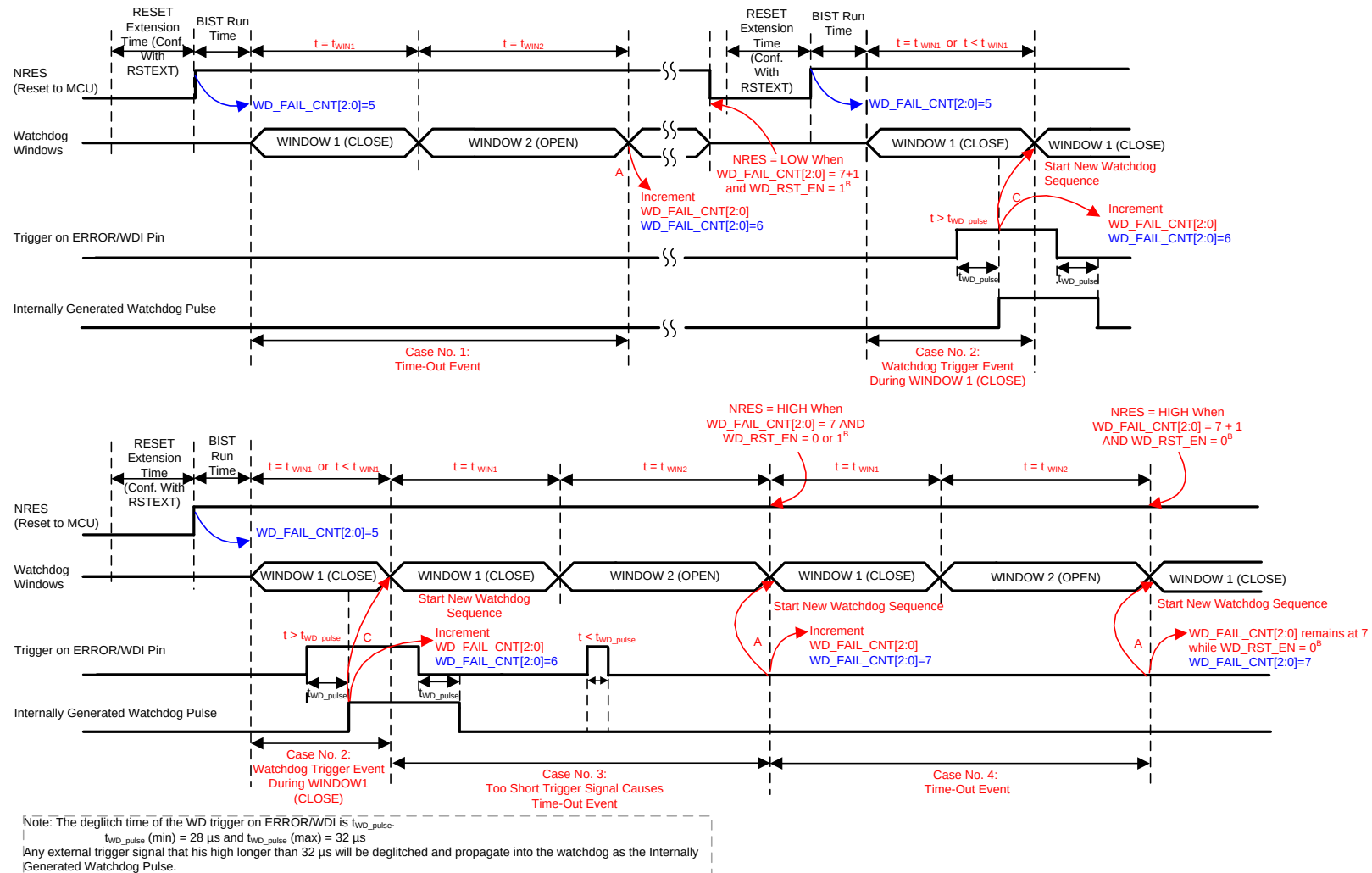
The watchdog trigger event is considered a *good-event* if received during a Window 2 (OPEN) window, and is considered a *bad-event* if received during Window 1 (CLOSE) window. A *good-event* ends the current watchdog sequence and starts a new watchdog sequence, therefore the MCU and device watchdog timing stay synchronized.

A *good-event*, *bad-event*, *time-out event*, power-up event, or power-down event ends the current watchdog sequence and starts a new watchdog sequence.



- A. When a *good event* is received in Window 2, 1 system clock-cycle (250 ns, typical) later the next watchdog sequence begins. Therefore the actual length of Window 2 depends on when the MCU sends the *good event*.

**Figure 5-6. Example Cases for Good-Events in Trigger Mode**



- When a *time-out event* occurs, 1 system clock-cycle (250 ns, typical) later, the next watchdog sequence begins.
- $WD\_RST\_EN = 0$  per default. To enable a reset from the watchdog once  $WD\_FAIL\_CNT[2:0] = 7 + 1$ ,  $WD\_RST\_EN$  must be set to 1. The notation  $WD\_FAIL\_CNT[2:0] = 7 + 1$  means the next (+ 1) *bad event* or *time-out event* if  $WD\_FAIL\_CNT[2:0] = 7$  while  $WD\_RST\_EN = 1$  will cause a transition to the RESET state. However, when  $WD\_RST\_EN = 0$ , the  $WD\_FAIL\_CNT[2:0]$  counter does not increment past 7 and the watchdog does not cause a transition to the RESET state.
- When a *bad event* is received in Window 1, 1 system clock-cycle (250 ns, typical) later the next watchdog sequence begins. Therefore the actual length of Window 1 depends on when the MCU sends the *bad event*.

**Figure 5-7. Example Cases for *Bad-Event* and *Time-out* Events in Trigger Mode**

### 5.4.15 Q&A Mode

Setting the WD\_CFG bit in the SAFETY\_FUNC\_REG register to 1 when the device is in the DIAGNOSTIC state configures the watchdog for Q&A (question and answer) mode. In Q&A mode, the device provides a *question* (or *TOKEN*) for the MCU in the WD\_TOKEN\_VALUE register. The MCU performs a fixed series of arithmetic operations on the question to calculate the required 32-bit answer. This answer is split into four answer bytes or responses. The MCU writes these answer bytes through SPI one byte at a time into the WD\_ANSWER register. The device verifies that the MCU returned the answer bytes within the specified timing windows, and that the answer bytes are correct.

A *good event* occurs when the MCU sends the correct answer bytes calculated for the current question within the correct watchdog window and in the correct order.

A *bad event* occurs when one of the events that follows occur:

- The MCU sends the correct answer bytes, but not in the correct watchdog window.
- The MCU sends incorrectly calculated answer bytes.
- The MCU returns correct answer bytes in the wrong order (sequence).

If the MCU stops sending answer bytes during the watchdog sequence, the watchdog considers this lack of response from the MCU a *time-out event* (no response event). This sets the TIME\_OUT status bit (bit 1 in the WD\_STATUS register) and increments the watchdog fail counter. Immediately following a *time-out event* a new watchdog sequence is started.

The TIME\_OUT flag can be useful for the MCU software to resynchronize the watchdog answer timing to the required device watchdog timing. When resynchronizing in this way, the MCU detects the TIME\_OUT flag being set. The TIME\_OUT flag being set indicates the *time-out event* and the start of a new watchdog sequence. The MCU should send the answer bytes with timing so they will be in the correct windows of the new watchdog sequence.

---

#### NOTE

If an active SPI frame (nCS is low) is present when the *time-out event* occurs, the TIME\_OUT flag is not latched (set) in the WD\_STATUS register, but the watchdog fail counter is still incremented. Because the TIME\_OUT flag is not latched this impacts the resynchronization ability of the MCU and status monitoring. It is recommended to use the synchronization procedure outlined in section [Section 5.4.13](#).

---

#### NOTE

In Q&A mode, each watchdog sequence starts with Window 1 (OPEN) followed by Window 2 (CLOSE). The OPEN and CLOSE references for Q&A mode are reversed with respect to those of trigger mode, but the order of the Window 1 and Window 2 is the same as are the registers containing the setting for each window, WD\_WIN1\_CFG and WD\_WIN2\_CFG.

---

#### 5.4.15.1 Watchdog Q&A Related Definitions

The Q&A mode definitions are:

**Question (Token)** The question (token) is a 4-bit word (see [Section 5.4.15.3](#)).

The watchdog provides the question (token) to the MCU when the MCU reads the question (TOKEN[3:0]) from the WD\_TOKEN\_VALUE register.

The MCU can request each new question (token) at the start of the watchdog sequence, but this is not required to calculate the answer. The MCU can also generate the question by implementing the question generation circuit as shown in [Figure 5-9](#). Nevertheless, the answer and, therefore the answer bytes, are always based on the question generated inside the watchdog of the device. So, if the MCU generates a wrong question and gives answer bytes calculated from a wrong question, the watchdog detects a *bad event*.

A new question (token) is generated only when a *good event* occurred in the previous watchdog sequence causing the token counter (internal counter) to increment and generate

a new question (token) as shown in figure [Figure 5-9](#).

**Answer (Response)** The answer (response) is a 32-bit word that is split into four answer bytes or responses: Answer-3 (WD\_TOKEN\_RESP\_3), Answer-2 (WD\_TOKEN\_RESP\_2), Answer-1 (WD\_TOKEN\_RESP\_1), and Answer-0 (WD\_TOKEN\_RESP\_0).

The watchdog receives an answer byte when the MCU writes to the watchdog answer register (the WD\_ANSW[7:0] bits in the WD\_ANSWER register).

For each question, the watchdog requires four correct answer bytes from the MCU in the correct timing and order (sequence). Answer-3, Answer-2, and Answer-1 can be in Window 1 or Window 2 in the correct order, and Answer-0 must be in Window 2 to be detected as a *good event*.

#### 5.4.15.2 Watchdog Sequence in Q&A Mode

The watchdog sequence in Q&A mode ends after the MCU writes the fourth answer byte, Answer-0 (WD\_TOKEN\_RESP\_0), or after a time-out event. A new watchdog sequence starts after the previous watchdog sequence ends.

The window duration times of Window 1 (OPEN) and Window 2 (CLOSE) are programmed through the WD\_WIN1\_CFG and WD\_WIN2\_CFG registers when the device is in the DIAGNOSTIC state. In Q&A mode, the window duration time are as follows:

$$t_{WOW\_MIN} (Q\&A \text{ mode}) = t_{WIN1\_MIN}$$

where

- WOW is a watchdog OPEN window

(11)

$$t_{WOW\_MAX} (Q\&A \text{ mode}) = t_{WIN1\_MAX}$$

where

- WOW is a watchdog OPEN window

(12)

$$t_{WCW\_MIN} (Q\&A \text{ mode}) = t_{WIN2\_MIN}$$

where

- WCW is a watchdog CLOSE window

(13)

$$t_{WCW\_MIN} (Q\&A \text{ mode}) = t_{WIN2\_MIN}$$

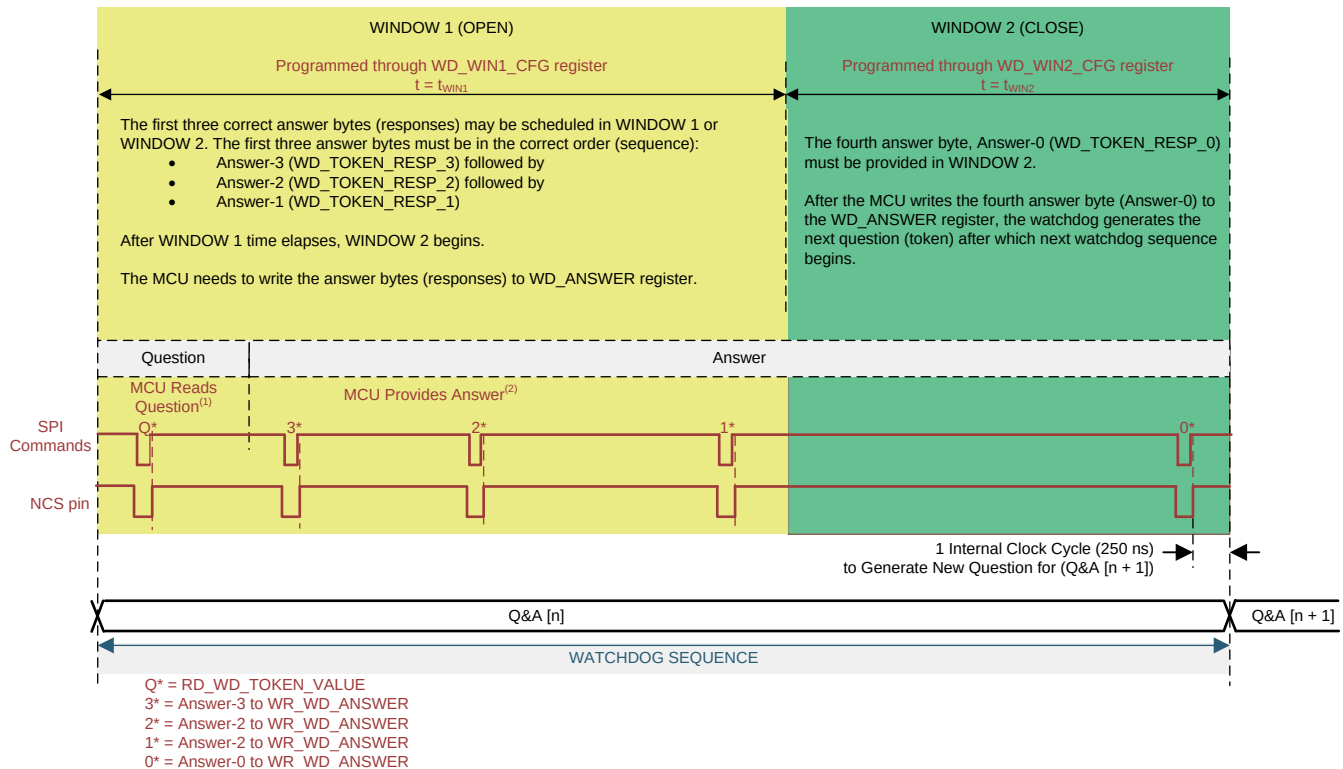
where

- WCW is a watchdog CLOSE window

(14)

Use [Equation 1](#) and [Equation 2](#) to calculate the minimum and maximum values for the  $t_{WIN1} = t_{WOW}$  time period. Use [Equation 3](#) and [Equation 4](#) to calculate the minimum and maximum values for the  $t_{WIN2} = t_{WCW}$  time period.

Writing a new Window 1 or Window 2 time to the WD\_WIN1\_CFG or WD\_WIN2\_CFG register immediately begins a new watchdog sequence and increments the watchdog fail counter. A new watchdog sequence is started by a write even when WD\_WIN1\_CFG register and the WD\_WIN2\_CFG SPI register are locked because the device is not in DIAGNOSTIC state or the SPI command SW\_LOCK is blocking a write update to the register values.



- (1) The MCU is not required to read the question (token). The MCU can begin giving the correct answer bytes Answer-3, Answer-2, Answer-1, anywhere in Window 1 or Window 2. The new question (token) is generated and a new watchdog sequence started within 1 system clock cycle after the final Answer-0 as long as the answer was a *good event*. A *bad event* or *time-out event* causes a new watchdog sequence to start, however a new question (token) is not generated.
- (2) The MCU can put other SPI commands in-between the WR\_WD\_ANSWER commands (even rerequesting the question). These SPI commands have no influence on the detection of a *good event*, as long as the four correct answer bytes are in the correct order, and the fourth correct answer byte is provided in Window 2.

**Figure 5-8. Watchdog Sequence in Q&A Mode**

#### 5.4.15.3 Question (Token) Generation

The watchdog uses a 4-bit token counter (TOKEN\_CNT[3:0] bits in [Figure 5-9](#)), and a 4-bit Markov chain to generate a 4-bit question (token). The MCU can read this question in the WD\_TOKEN\_VALUE register, TOKEN[3:0] bits. The watchdog generates a new question when the token counter increments, which only occurs when the watchdog detects a *good event*. The watchdog does not generate a new question when it detects a *bad event* or a *time-out event*. The watchdog does not generate a new question for a watchdog sequence that starts after the MCU writes to the WD\_WIN1\_CFG or WD\_WIN2\_CFG registers.

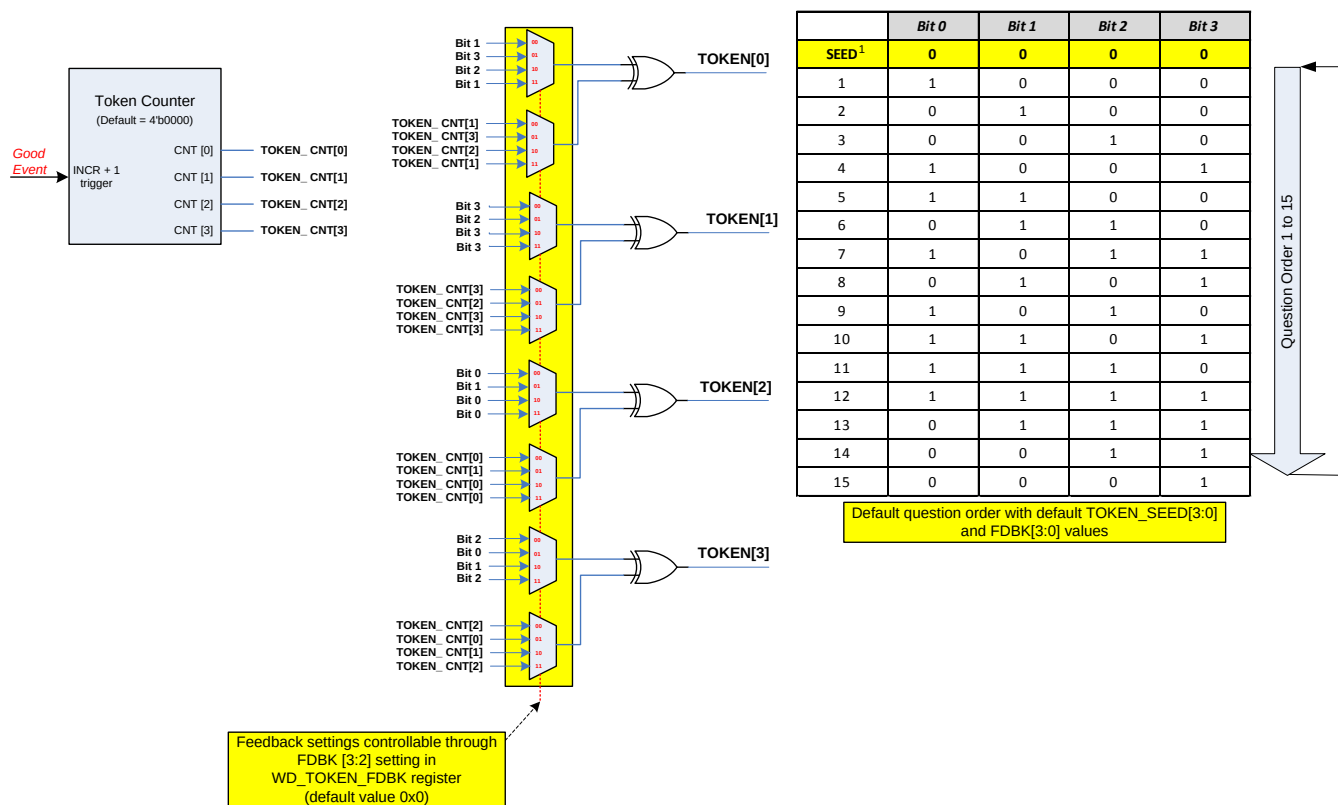
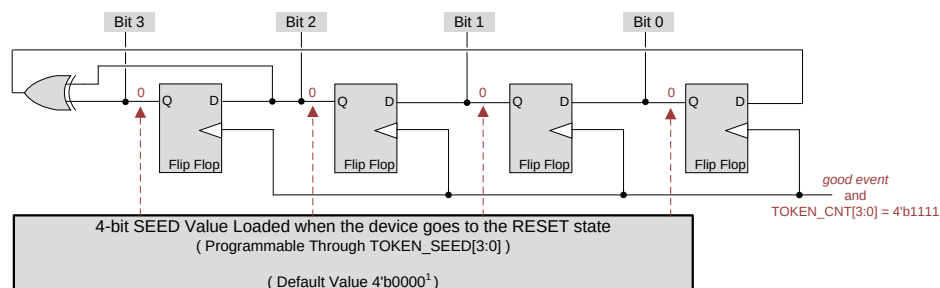
The token counter provides a clock pulse to the Markov chain when it transitions from 1111b to 0000b. The question counter and the Markov chain are set to the singular default value of 0000b when the device completes the LBIST (either a manual LBIST run or the automotive LBIST run initiated on the transition from the RESET to DIAGNOSTIC state). To leave the singular point, the feedback logic combination is implemented.

[Figure 5-9](#) shows the logic combination for the question (token) generation. The question is in the WD\_TOKEN\_VALUE register, TOKEN[3:0] bits.

The logic combination of the token counter with the WD\_ANSW\_CNT[1:0] status bits (in the WD\_STATUS register) generates the reference answer bytes as shown in [Figure 5-9](#).

4-bit LFSR Polynomial Equation<sup>1</sup>FDBK[2:1] = 2b'00:  $y = x4 + x3 + 1$  (Default Value)FDBK[2:1] = 2b'01:  $y = x4 + x2 + 1$ FDBK[2:1] = 2b'10:  $y = x3 + x2 + 1$ FDBK[2:1] = 2b'11:  $y = x4 + x3 + x2 + 1$ 

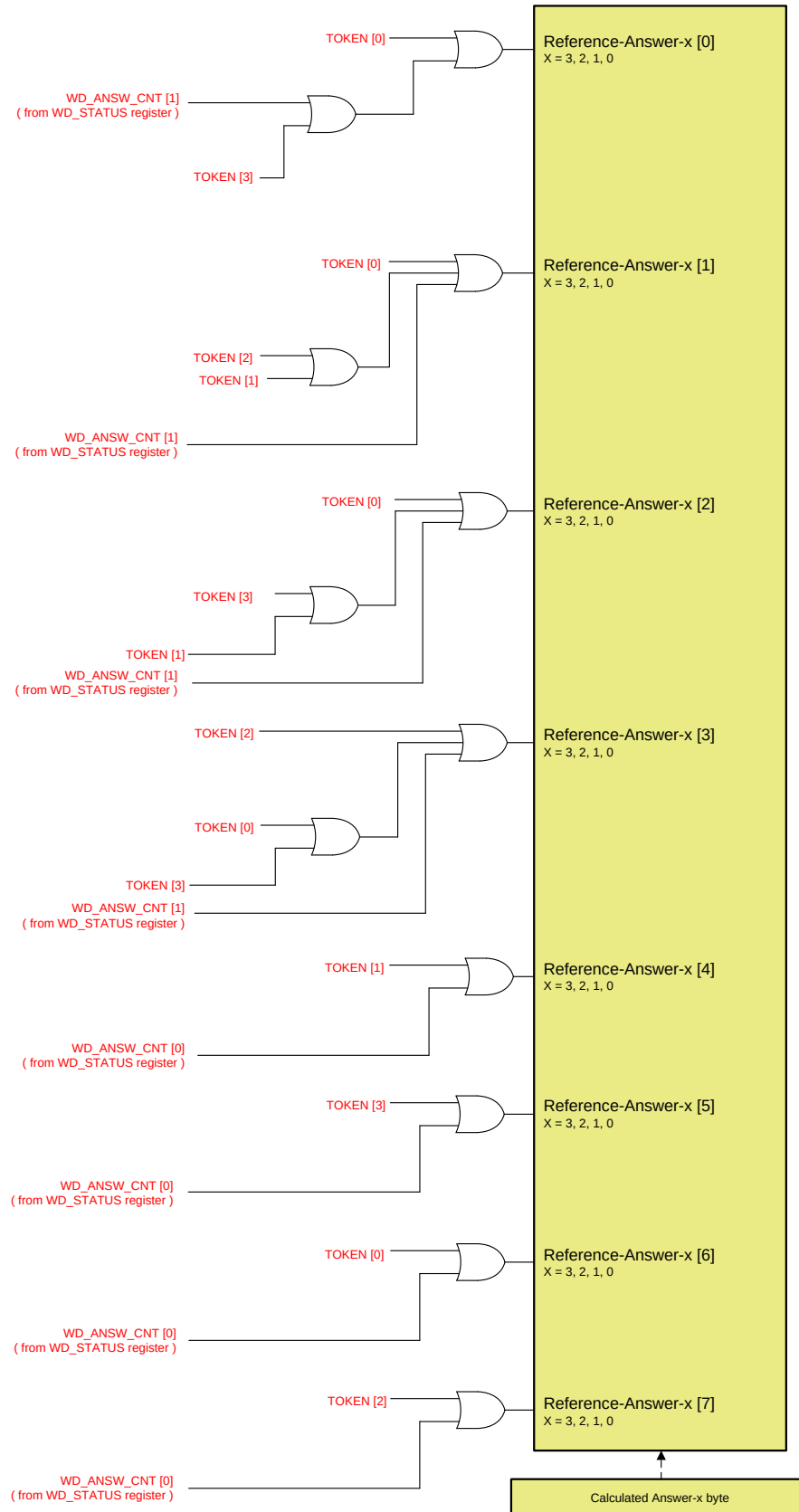
## Equivalent for Default LFSR Polynomial (Default FDBK value)



(1) A value of 0000b is a special seed and equates to 0001b, including the default loading of 0000b during power up.

**Figure 5-9. Watchdog Question (Token) Generation**





**Figure 5-10. Watchdog Answer Calculation**

#### 5.4.15.4 Answer Comparison and Reference Answer

The 2-bit, watchdog-answer counter, WD\_ANSW\_CNT[1:0], in the WD\_STATUS register counts the number of received answer bytes and controls the generation of the reference Answer-x byte as shown in [Figure 5-10](#). At the start of each watchdog sequence, the default value of the WD\_ANSW\_CNT[1:0] is 11b to indicate that the watchdog expects the MCU to write Answer-3 (WD\_RESP\_3) in the WD\_ANSWER register.

##### 5.4.15.4.1 Sequence of the 2-bit Watchdog Answer Counter

The sequence of the 2-bit, watchdog answer counter, WD\_ANSW[1:0], is as follows for each counter value:

- WD\_ANSW\_CNT[1:0] = 11b:
  - The watchdog calculates reference Answer-3
  - A write access occurs: the MCU writes Answer-3 (WD\_TOKEN\_RESP\_3) byte in the WD\_ANSWER register.
  - The watchdog compares the reference Answer-3 with the Answer-3 byte in the WD\_ANSWER register.
  - The watchdog decrements the WD\_ANSW\_CNT[1:0] bits to 10b and updates the ANSWER\_ERR flag bit.
- WD\_ANSW\_CNT[1:0] = 10b:
  - The watchdog calculates reference Answer-2
  - A write access occurs: the MCU writes Answer-2 (WD\_TOKEN\_RESP\_2) byte in the WD\_ANSWER register.
  - The watchdog compares the reference Answer-2 with the Answer-2 byte in the WD\_ANSWER register.
  - The watchdog decrements the WD\_ANSW\_CNT[1:0] bits to 01b and updates the ANSWER\_ERR flag bit.
- WD\_ANSW\_CNT[1:0] = 01b:
  - The watchdog calculates reference Answer-1
  - A write access occurs: the MCU writes Answer-1 (WD\_TOKEN\_RESP\_1) byte in the WD\_ANSWER register.
  - The watchdog compares the reference Answer-1 with the Answer-1 byte in the WD\_ANSWER register.
  - The watchdog decrements the WD\_ANSW\_CNT[1:0] bits to 00b and updates the ANSWER\_ERR flag bit.
- WD\_ANSW\_CNT[1:0] = 00b:
  - The watchdog calculates reference Answer-0
  - A write access occurs: the MCU writes Answer-0 (WD\_TOKEN\_RESP\_0) byte in the WD\_ANSWER register.
  - The watchdog compares the reference Answer-0 with the Answer-0 byte in the WD\_ANSWER register.
  - The watchdog updates the ANSWER\_ERR flag bit.
  - The watchdog starts a new watchdog sequence and sets the WD\_ANSW\_CNT[1:0] to 11b.

**Table 5-11. Set of Questions (Tokens) and Corresponding Answer Bytes Using Default Setting of WD\_TOKEN\_FDBK Register**

| QUESTION (TOKEN)<br>IN<br>WD_TOKEN_VALUE<br>REGISTER | WD ANSWER (TO BE WRITTEN INTO WD_ANSW REGISTER) |                            |                            |                            |
|------------------------------------------------------|-------------------------------------------------|----------------------------|----------------------------|----------------------------|
|                                                      | Answer-3 (WD_TOKEN_RESP_3)                      | Answer-2 (WD_TOKEN_RESP_2) | Answer-1 (WD_TOKEN_RESP_1) | Answer-0 (WD_TOKEN_RESP_0) |
| TOKEN [3:0]                                          | WD_ANSW_CNT<br>[1:0] = 11b                      | WD_ANSW_CNT<br>[1:0] = 10b | WD_ANSW_CNT<br>[1:0] = 01b | WD_ANSW_CNT<br>[1:0] = 00b |
| 0h                                                   | FFh                                             | 0Fh                        | F0h                        | 00h                        |
| 1h                                                   | B0h                                             | 40h                        | BFh                        | 4Fh                        |
| 2h                                                   | E9h                                             | 19h                        | E6h                        | 16h                        |
| 3h                                                   | A6h                                             | 56h                        | A9h                        | 59h                        |
| 4h                                                   | 75h                                             | 85h                        | 7Ah                        | 8Ah                        |
| 5h                                                   | 3Ah                                             | CAh                        | 35h                        | C5h                        |
| 6h                                                   | 63h                                             | 93h                        | 6Ch                        | 9Ch                        |
| 7h                                                   | 2Ch                                             | DCh                        | 23h                        | D3h                        |
| 8h                                                   | D2h                                             | 22h                        | DDh                        | 2Dh                        |
| 9h                                                   | 9Dh                                             | 6Dh                        | 92h                        | 62h                        |
| Ah                                                   | C4h                                             | 34h                        | CBh                        | 3Bh                        |
| Bh                                                   | 8Bh                                             | 7Bh                        | 84h                        | 74h                        |
| Ch                                                   | 58h                                             | A8h                        | 57h                        | A7h                        |
| Dh                                                   | 17h                                             | E7h                        | 18h                        | E8h                        |
| Eh                                                   | 4Eh                                             | BEh                        | 41h                        | B1h                        |
| Fh                                                   | 01h                                             | F1h                        | 0Eh                        | FEh                        |

#### 5.4.15.5 Watchdog Q&A Mode Sequence Events and WD\_STATUS Register Updates

The watchdog sequence events are as follows for the different scenarios listed:

- A *good event* occurs when all answer bytes are correct in value (the ANSWER\_ERR bit is cleared to 0) and timing. For such a good event, then the events that follow occur:
  - The watchdog fail counter, WD\_FAIL\_CNT[2:0], decrements by one.
  - The token counter increments by one, causing a new question (token) to be generated.
  - The SEQ\_ERR bit resets.
  - The ANSWER\_EARLY bit resets.
- A *bad event* occurs when all answer bytes are correct in value (the ANSWER\_ERR bit is cleared to 0) but not in correct timing. For such a bad event, then the events that follow occur:
  - The watchdog fail counter, WD\_FAIL\_CNT[2:0], increments by one.
  - The token counter does not change, thus the question (token) does not change.
  - The SEQ\_ERR bit is set.
  - The ANSWER\_EARLY bit is set.
- A *bad event* occurs when one or more of the answer bytes are not correct in value (the ANSWER\_ERR bit is set to 1) but in correct timing. For such a bad event, then the events that follow occur:
  - The watchdog fail counter, WD\_FAIL\_CNT[2:0], increments by one.
  - The token counter does not change, thus the question (token) does not change.
  - The SEQ\_ERR bit is set
  - The ANSWER\_EARLY bit is reset

- A *bad event* occurs when one or more of the answer bytes are not correct in value (the ANSWER\_ERR status bit is set to 1) and not in correct timing. For such a bad event, then the events that follow occur:
  - The watchdog fail counter, WD\_FAIL\_CNT[2:0], increments by one
  - The token counter does not change, thus the question (token) does not change.
  - The SEQ\_ERR bit is set.
  - The ANSWER\_EARLY bit is set.
- In case a *time-out event* occurs, then the events that follow occur:
  - The watchdog fail counter, WD\_FAIL\_CNT[2:0], increments by one.
  - The token counter does not change, thus the question (token) does not change.
  - The TIME\_OUT bit is set.
- In case the MCU writes to registers WD\_WIN1\_CFG or WD\_WIN2\_CFG, the events that follow occur:
  - The watchdog fail counter, WD\_FAIL\_CNT[2:0], increments by one.
  - The WD\_CFG\_CHG bit is set.

**Table 5-12. WD\_STATUS Bits Versus Possible Watchdog Sequence Events**

| WATCHDOG SEQUENCE EVENTS      |                                          |                                         |                                             |                                        | WD_STATUS REGISTER BITS |         |          |              |
|-------------------------------|------------------------------------------|-----------------------------------------|---------------------------------------------|----------------------------------------|-------------------------|---------|----------|--------------|
| All MCU Answer Bytes Correct? | Answer-0 Arrived During WINDOW 2 (CLOSE) | Answer-0 Arrived During WINDOW 1 (OPEN) | Time-out Occurred While Waiting for Answer? | WINDOW 1 or WINDOW 2 Duration Changed? | WD_CFG_CHG              | SEQ_ERR | TIME_OUT | ANSWER_EARLY |
| Yes                           | Yes                                      | No                                      | No                                          | No                                     | 0                       | 0       | 0        | 0            |
| Yes                           | No                                       | Yes                                     | No                                          | No                                     | 0                       | 0       | 0        | 1            |
| No                            | Yes                                      | No                                      | No                                          | No                                     | 0                       | 1       | 0        | 0            |
| No                            | No                                       | Yes                                     | No                                          | No                                     | 0                       | 1       | 0        | 1            |
| Yes (first 3 Answer-x)        | No                                       | No                                      | Yes                                         | No                                     | 0                       | 0       | 1        | 0            |
| No                            | No                                       | No                                      | Yes                                         | No                                     | 0                       | 1       | 1        | 0            |
| —                             | —                                        | —                                       | —                                           | Yes                                    | 1                       | 0       | 0        | 0            |

### 5.4.16 MCU Error Signal Monitor (MCU ESM)

This block monitors the external MCU error conditions signaled from the MCU to the device through the ERROR/WDI input pin. The MCU ESM is configurable to monitor two different signaling options depending which functional safety architecture MCU family is being monitored and how the specific MCU family indicates on the error or fault output pin improper operation. The MCU ESM mode is selected through the ERROR\_CFG bit in the SAFETY\_FUNC\_CFG register.

In TMS570 mode the ESM detects a low-pulse signal with a programmable low-pulse duration threshold (see [Section 5.4.16.1](#)). This mode is selected when the ERROR\_CFG bit is set to 1. In PWM mode the ESM detecting a PWM signal with a programmable frequency and duty cycle (see [Section 5.4.16.2](#)). This mode is selected when the ERROR\_CFG bit is cleared to 0 (default). PWM mode can be used as an external clock-monitor function.

The MCU ESM is deactivated by default. To activate it, clear the NO\_ERROR bit to 0 in the SAFETY\_CHECK\_CTRL register.

---

#### NOTE

Activating the MCU ESM is only recommended when the watchdog is configured in Q&A mode, otherwise the ERROR/WDI pin is used both for watchdog trigger input and MCU error signaling.

---

The low-signaling duration threshold (for TMS570 mode) or the expected PWM low-pulse duration (for PWM mode) is set through the SAFETY\_ERR\_PWM\_L register. The expected PWM high-pulse duration (for PWM mode) is set through the SAFETY\_ERR\_PWM\_H register. A detected MCU signaling error is indicated when the ERROR\_PIN\_FAIL bit in the SAFETY\_ERR\_STAT register is set to 1.

---

#### NOTE

An update to a SAFETY\_ERR\_PWM\_x register (only possible in the DIAGNOSTIC state) has an immediate effect. Therefore, if the MCU writes a new value to the SAFETY\_ERR\_PWM\_x register which is less than the value of the current pulse-duration counter value, the MCU ESM immediately detects an error condition on the ERROR/WDI pin. The pulse duration counter then reinitializes to 0 and sets the ERROR\_PIN\_FAIL bit to 1.

---

When the TPS65381A-Q1 device is in the DIAGNOSTIC state, the MCU can emulate a signaling error (emulated fault-injection) for a diagnostic check of the error-signal monitor by checking the status of the ERROR\_PIN\_FAIL bit while the NO\_ERROR bit is cleared to 0 (MCU ESM enabled) without a transition to the SAFE state.

**NOTE**

To perform an MCU ESM diagnostic check of the pin while in the DIAGNOSTIC state the following procedure can be used. The ERROR/WDI pin is edge triggered.

1. Clear the ERROR\_PIN\_FAIL bit by clearing it to 0 in the SAFETY\_ERR\_STAT register.
2. Verify the ERROR\_PIN\_FAIL bit is not reset to 1 when the MCU ESM is enabled.
3. Inject a failure on the ERROR/WDI pin specific to the MCU ESM mode of operation.
4. Verify the ERROR\_PIN\_FAIL bit is set to 1 and the ENDRV pin is low even if the ENABLE\_DRV bit is set to 1.
5. Remove the injected failure.
6. Write 0 to clear the ERROR\_PIN\_FAIL bit.
7. Confirm the ERROR\_PIN\_FAIL bit was cleared by reading back the SAFETY\_ERR\_STAT register.
8. Confirm the ENDRV pin returned HIGH when the ENABLE\_DRV bit is set to 1, assuming no other conditions exist that block ENDRV from being HIGH (see [Figure 5-14](#)).

When the TPS65381A-Q1 device is in the ACTIVE state, a detected MCU signaling error causes a transition to the SAFE state. A dedicated 4-bit error counter, the DEV\_ERR\_CNT[3:0] bits in the SAFETY\_ERR\_STAT register, counts the transitions from the ACTIVE state to the SAFE state.

The module is covered by the logic BIST (LBIST).

**5.4.16.1 TMS570 Mode**

An error condition is detected when the ERROR/WDI pin remains low longer than the programmed amount of time set by the SAFETY\_ERR\_PWM\_L register. The programmable time range is 5  $\mu$ s to 1.28 ms (typical), with 5- $\mu$ s steps ( $\pm 5\%$ ).

The SAFETY\_ERR\_PWM\_L register must be set to the desired value based on the maximum required time for the TMS570 MCU to detect an error or fault and to potentially recover from or correct the error or fault.

The LOW duration time is as follows:

$$t_{\text{TMS570\_LOW\_MIN}} = (\text{PWML}[7:0]) \times 5 \mu\text{s} \times 0.95 \quad (15)$$

$$t_{\text{TMS570\_LOW\_MAX}} = (\text{PWML}[7:0] + 1) \times 5 \mu\text{s} \times 1.05 \quad (16)$$

Use [Equation 15](#) and [Equation 16](#) to calculate the minimum and maximum values for the LOW duration,  $t_{\text{TMS570\_LOW}}$ . [Figure 5-11](#) shows the error-detection case scenarios.

**NOTE**

The SAFETY\_ERR\_PWM\_L register (PWML[7:0]) should be configured with a minimum of 1 (01h) in the register.

The low-pulse monitoring on the ERROR/WDI pin is implemented as follows:

- When the NO\_ERROR bit is cleared to 0, every falling edge on the ERROR/WDI pin reinitializes the low-pulse duration counter to 0 within one system clock-cycle (250 ns  $\pm 5\%$ ).
- After reinitialization, the low-pulse counter restarts one system clock-cycle (250 ns  $\pm 5\%$ ).
- The low-pulse duration counter increases every 5  $\mu$ s (with  $\pm 5\%$  accuracy) as long as the ERROR/WDI pin is low. A rising edge on the ERROR/WDI pin stops the low-pulse duration counter.
- When low-pulse duration counter is equal to the SAFETY\_ERR\_PWM\_L register setting, an error is detected.

The ERROR\_PIN\_FAIL bit in the SAFETY\_ERR\_STAT register is set within one system clock cycle (250 ns  $\pm 5\%$ ) after detecting an MCU signaling error. When the device is in the ACTIVE state, a transition to the SAFE state occurs after one more system clock-cycle.

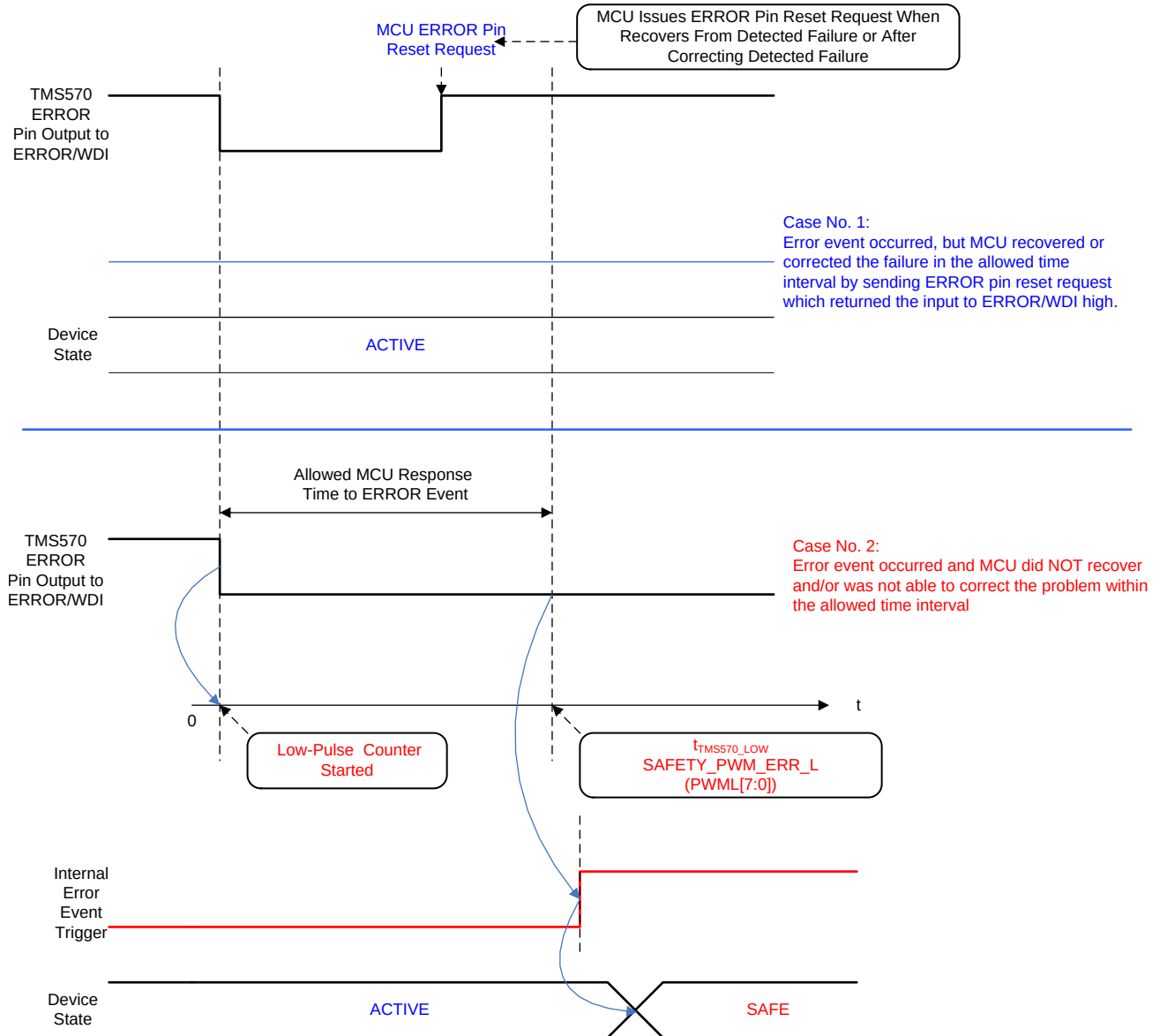


Figure 5-11. Error Detection Case Scenarios in TMS570 Mode

#### 5.4.16.2 PWM Mode

An error condition is detected when one of the following occurs on the ERROR/WDI pin:

- The ERROR/WDI pin high-pulse duration exceeds the threshold value programmed by the PWM\_H register.
- The ERROR/WDI pin low-pulse duration exceeds the threshold value programmed by the PWM\_L register.

The MCU ESM does NOT detect an MCU signaling error on the ERROR/WDI pin if both of the following occurs:

- The ERROR pin high-pulse duration is less than the threshold value programmed by the PWM\_H register.
- The ERROR pin low-pulse duration is less than the threshold value programmed by the PWM\_L register.

The programmable time range for the expected HIGH and LOW pulse duration is 15  $\mu$ s to 3.8 ms (typical), with 15- $\mu$ s resolution steps ( $\pm 5\%$ ). The HIGH and LOW pulse duration times are programmed through the SAFETY\_ERR\_PWM\_H and SAFETY\_ERR\_PWM\_L registers when the device is in the DIAGNOSTIC state. The pulse duration time are as follows:

$$t_{\text{PWM\_HIGH\_MIN}} = (\text{PWMH}[7:0]) \times 15 \mu\text{s} \times 0.95 \quad (17)$$

$$t_{\text{PWM\_HIGH\_MAX}} = (\text{PWMH}[7:0] + 1) \times 15 \mu\text{s} \times 1.05 \quad (18)$$

$$t_{\text{PWM\_LOW\_MIN}} = (\text{PWML}[7:0]) \times 15 \mu\text{s} \times 0.95 \quad (19)$$

$$t_{\text{PWM\_LOW\_MAX}} = (\text{PWML}[7:0] + 1) \times 15 \mu\text{s} \times 1.05 \quad (20)$$

Use Equation 17 and Equation 18 to calculate the minimum and maximum values for the HIGH pulse duration,  $t_{\text{PWM\_HIGH}}$ . Use Equation 19 and Equation 20 to calculate the minimum and maximum values for the LOW pulse duration,  $t_{\text{PWM\_LOW}}$ .

#### NOTE

The SAFETY\_ERR\_PWM\_H (PWMH[7:0]) and SAFETY\_ERR\_PWM\_L (PWML[7:0]) register should be configured with a minimum of 1 (01h) in the registers.

The monitoring of the high-pulse duration and low-pulse duration is implemented as follows:

LOW pulse monitoring:

- Every falling edge on the ERROR/WDI pin, or setting the NO\_ERROR bit from 1 to 0 when the ERROR/WDI pin is low, reinitializes the low-pulse duration counter to 0 within one system clock-cycle (250 ns  $\pm 5\%$ ).
- After reinitialization, the low-pulse counter restarts after one system clock-cycle (250 ns  $\pm 5\%$ ).
- The low-pulse duration counter increases every 15  $\mu$ s ( $\pm 5\%$ ) while the ERROR/WDI pin remains low.
- When the low-pulse duration counter is equal to the SAFETY\_ERR\_PWM\_L register setting, an error is detected.

HIGH pulse monitoring:

- Every rising edge on the ERROR/WDI pin, or setting the NO\_ERROR bit from 1 to 0 when the ERROR/WDI pin is high, reinitializes the high-pulse duration counter to 0 within one system clock-cycle (250 ns  $\pm 5\%$ ).
- After reinitialization, the high-pulse counter restarts after one system clock-cycle (250 ns  $\pm 5\%$ ).
- The high-pulse duration counter increases every 15  $\mu$ s (with  $\pm 5\%$  accuracy) while the ERROR/WDI pin remains high.
- When the high-pulse duration counter is equal to the SAFETY\_ERR\_PWM\_H register setting, an error is detected.



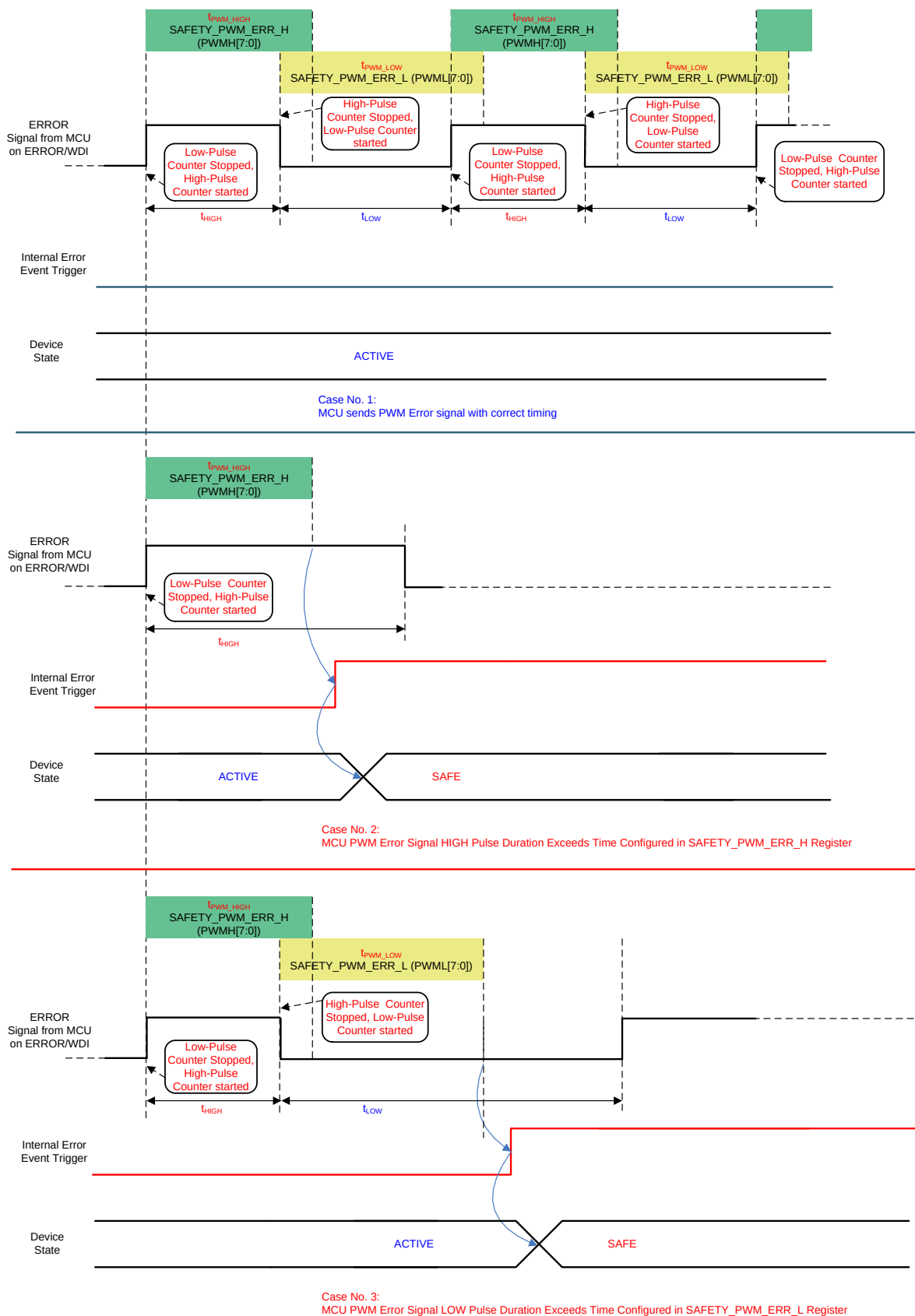
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**NOTE**

The ERROR/WDI pin is edge triggered, to synchronize the MCU to the MCU ESM module, while in the DIAGNOSTIC state the MCU should start sending the desired PWM signal. On the first falling or rising edge the MCU ESM detects the edge and starts the internal timers in sync with the edge so the MCU and MCU ESM are synchronized. The MCU ESM resynchronizes to the MCU on every rising and falling edge. While in the DIAGNOSTIC state, when synchronization has occurred the ERROR\_PIN\_FAIL flag should be cleared.

---

The ERROR\_PIN\_FAIL bit in the SAFETY\_ERR\_STAT register is set within one system clock cycle (250 ns  $\pm$ 5%) after detecting an MCU signaling error. When the device is in the ACTIVE state, a transition to the SAFE state occurs after one more system clock-cycle.



**Figure 5-12. Error Detection Case Scenarios in PWM Mode**

### 5.4.17 Device Configuration Register Protection

This function offers a mechanism to help protect safety SPI-mapped registers by means of SPI write-access protection and CRC check.

The register access protection includes two distinctive features:

- A register cannot be written after write-access lock protection is set. The lock is cleared by software or by a power-on reset.
- CRC protection for configuration registers.

A CRC occurs on safety data after a SPI write updates to verify the SPI register contents are correctly programmed. The CRC controller is a diagnostic module, which performs the CRC to verify the integrity of the SPI-mapped register space. A signature representing the content of the safety registers is obtained when the content is read into the CRC controller. The responsibility of the CRC controller is to calculate the signature for a set of data and then compare the calculated signature value against a predetermined good-signature value. The predetermined CRC signature value is stored in the SAFETY\_CFG\_CRC register. The external MCU uses the SAFETY\_CHECK\_CTRL register to enable a CRC check and the SAFETY\_STAT\_2 register to monitor the status. When enabled, a CRC check on the configuration registers is performed. In case of a detected signature error, the CFG\_CRC\_ERR flag is set in the SAFETY\_STAT\_2 SPI register. The device state and the ENDRV pin state remain unchanged. In case of a detected checksum error with the TPS65381A-Q1 device in the DIAGNOSTIC state, clearing the CFG\_CRC\_EN bit to 0 brings the TPS65381A-Q1 device into the SAFE state (the ENDRV pin is pulled low).

A standard CRC-8 polynomial is used:  $X^8 + X^2 + X^1 + 1$

The CRC monitor test is covered by a logic BIST.

A 64-bit string is protected by CRC. The following registers are protected:

- SAFETY\_FUNC\_CFG
- DEV\_REV
- SAFETY\_PWD\_THR\_CFG
- SAFETY\_ERR\_CFG
- WD\_TOKEN\_FDBK
- WD\_WIN2\_CFG
- WD\_WIN1\_CFG
- SAFETY\_ERR\_PWM\_L
- DEV\_CFG2
- DEV\_CFG1 (only bit number 6)

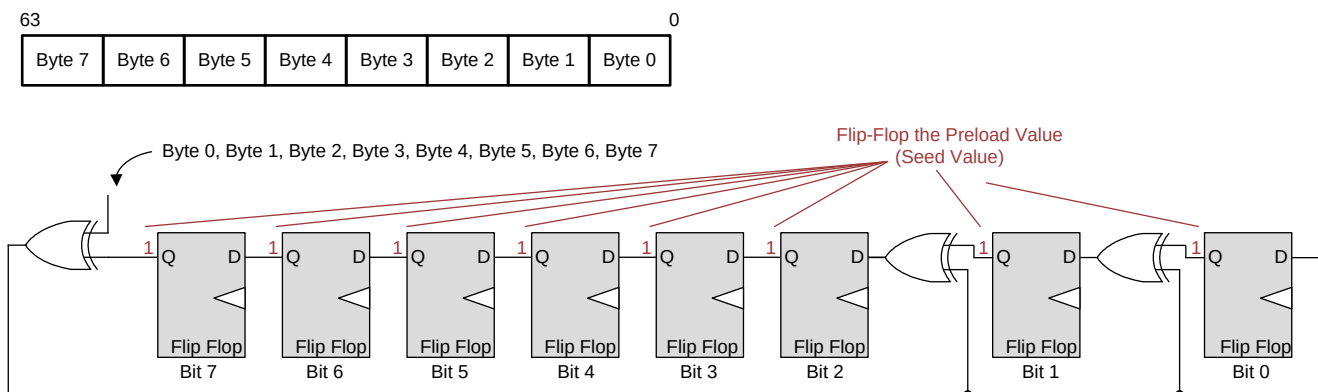
Table 5-13 lists the CRC bus structure.

**Table 5-13. CRC Bus Structure**

| REGISTER NAME            | 64-BIT BUS ORDERING |
|--------------------------|---------------------|
| SAFETY_FUNC_CFG [6:0]    | [63:57]             |
| DEV_REV [7:0]            | [56:49]             |
| SAFETY_PWD_THR_CFG [3:0] | [48:45]             |
| SAFETY_ERR_CFG [7:0]     | [44:37]             |
| WD_TOKEN_FDBK [7:0]      | [36:29]             |
| WD_WIN2_CFG [4:0]        | [28:24]             |
| WD_WIN1_CFG [6:0]        | [23:17]             |
| SAFETY_ERR_PWM_L [7:0]   | [16:9]              |
| DEV_CFG2 [7:0]           | [8:1]               |
| DEV_CFG1 [6]             | 0                   |

In the external MCU, the CRC calculation must be performed byte-wise, starting with the lowest byte of the 64-bit bus ordering value. The most significant bit is first in the bit order. The resulting CRC of one calculation is the seed value for the next calculation. The initial seed value is FFh. The CRC result of the eighth byte-wise calculation is the CRC signature value, which must be stored in the SAFETY\_CFG\_CRC register (see Figure 5-13).

64-Bit Bus Ordering Value:



**Figure 5-13. CRC Calculation Logic**

Table 5-14 lists some CRC calculation examples.

**Table 5-14. CRC Calculation Examples**

| 64-BIT BUS ORDERING VALUE | CRC-8 RESULT |
|---------------------------|--------------|
| 0000 0000 0000 0000h      | DBh          |
| FFFF FFFF FFFF FFFFh      | 0Ch          |
| 0A0A 0505 0A0A 0505h      | D4h          |
| 0505 0A0A 0505 0A0Ah      | 17h          |
| A0A0 5050 A0A0 5050h      | 2Bh          |
| 0A23 E000 18FE 7B80h      | 1Bh          |

In case the CRC controller detects a signature error on the configuration registers, care must be used when performing an EEPROM CRC afterwards. In case of a detected signature error in the configuration registers, the device reports an EEPROM signature error when the CFG\_CRC\_EN bit in the SAFETY\_CHECK\_CTRL register is cleared to 0 first before performing the EEPROM CRC by setting the EE\_CRC\_CHK bit in the SAFETY\_BIST\_CTRL register to 1, even when the EEPROM bits do not have an error. Therefore, when performing an EEPROM CRC after a CRC on the configuration registers, the steps must always occur in the following order:

1. Calculate CRC8 in the MCU and store it in the SAFETY\_CFG\_CRC register.
2. Set the CFG\_CRC\_EN bit in the SAFETY\_CHECK\_CTRL register to 1 to perform a CRC on the configuration registers.
3. After the SPI command sets the CFG\_CRC\_EN bit to 1 (for example, after rising edge on NCS), wait at least 2.1  $\mu$ s for the configuration register to complete the CRC.
4. Read the results of the configuration register CRC in the SAFETY\_STAT\_2 register, bit CFG\_CRC\_ERR. If continuous CRC on the configuration register must be performed, clear the CFG\_CRC\_EN bit in the SAFETY\_CHECK\_CTRL register to 0 and repeat beginning with [Step 1](#). If the CRC on the EEPROM registers must be performed, proceed to [Step 5](#).

---

#### NOTE

A correct EEPROM CRC afterwards (as described in [Step 5](#)) clears this CFG\_CRC\_ERR bit. Therefore, TI recommends reading out this CFG\_CRC\_ERR bit before performing the EEPROM CRC.

5. Set the EE\_CRC\_CHK bit in the SAFETY\_BIST\_CTRL register to 1 to perform the CRC on the EEPROM registers.
6. After the SPI command sets the EE\_CRC\_CHK bit to 1 (for example, after rising edge on NCS), wait at least 811  $\mu$ s for the EEPROM CRC to finish.
7. Completion of the EEPROM CRC is observed by reading the EE\_CRC\_CHK bit. When the EEPROM CRC is complete, this EE\_CRC\_CHK bit is cleared to 0.
8. Clear the CFG\_CRC\_EN bit in the SAFETY\_CHECK\_CTRL register to 0
9. Read the results of the EEPROM CRC in the SAFETY\_STAT\_2 register, bit EE\_CRC\_ERR.
10. Go back to [Step 1](#).

---

#### NOTE

Returning to [Step 1](#) is not required; returning to [Step 2](#) is also an option.

---

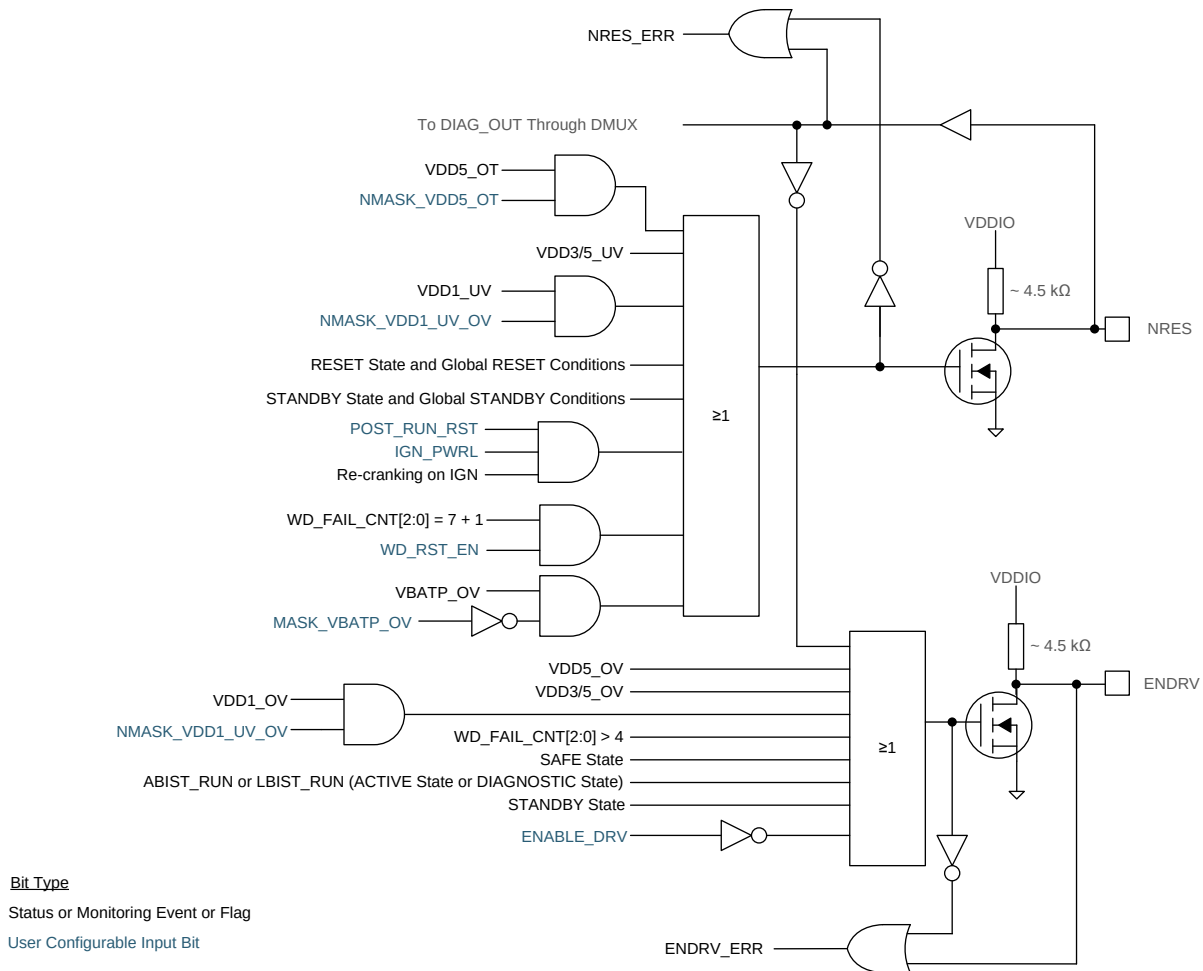
#### NOTE

While in the DIAGNOSTIC state, a check can be performed to confirm the CFG\_CRC\_ERR bit is set to 1 on a mismatch between the value stored in the SAFETY\_CFG\_CRC register and the value that is calculated from the configuration registers covered by the CRC8. If the CFG\_CRC\_EN is cleared while the CFG\_CRC\_ERR bit is set to 1, then the device transitions to the SAFE state, set the EE\_CRC\_ERR bit and clear the CFG\_CRC\_EN bit. To avoid this transition to the SAFE state, the CFG\_CRC\_ERR bit must be cleared by running the EEPROM CRC by setting the EE\_CRC\_CHK bit. While the EEPROM CRC is running, the EE\_CRC\_ERR bit is set. Assuming the EEPROM CRC was good, both the EE\_CRC\_ERR and CFG\_CRC\_ERR bits are cleared. To check if the CFG\_CRC\_ERR bit is 0 for a matching CRC, the matching CRC value should be stored in the SAFETY\_CFG\_CRC register. Then the CFG\_CRC\_EN bit must be cleared to 0 and set again to 1 which reruns the CRC on the configuration registers, resulting in the CFG\_CRC\_ERR bit being 0.

---

### 5.4.18 Enable and Reset Driver Circuit

Figure 5-14 shows the reset and enable circuit.



**Figure 5-14. Reset and Enable Circuit**

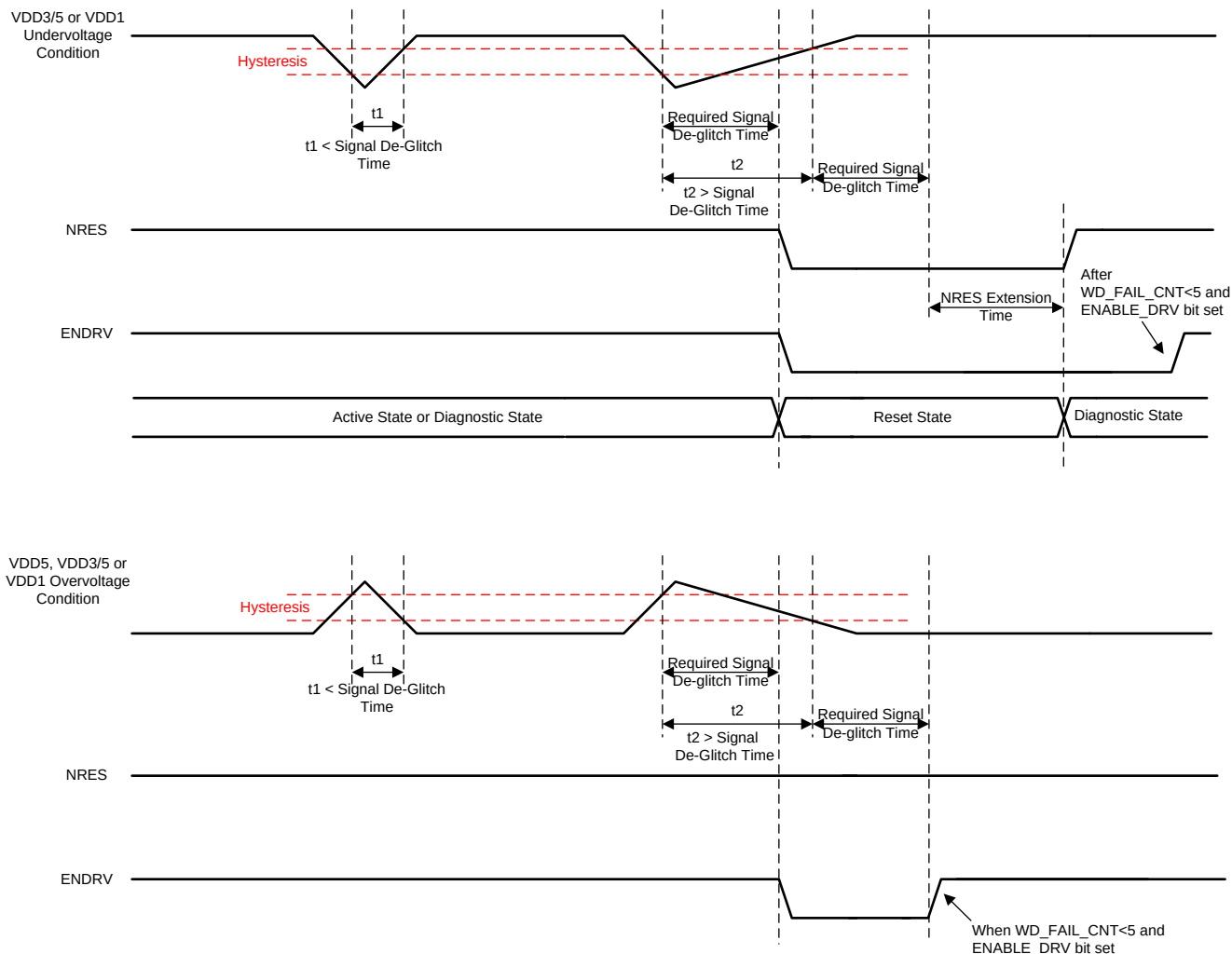
The ENDRV pin features a read-back circuit to compare the external ENDRV level with the internally applied ENDRV level. This feature detects any possible failure in the ENDRV pullup or pulldown components. A failure is detected by the MCU through the ENDRV\_ERR bit (bit 1 in the SAFETY\_STAT\_4 register).

The ENDRV pin is pulled low for the ABIST duration time (approximately 300  $\mu$ s) when activating the ABIST function after the ENDRV output is turned on and driven high. This is part of ENDRV diagnostics to validate all monitoring functions that disable the ENDDRV output and confirm that the ENDRV output is controllable by using the ENDRV read-back path.

The NRES pin features a readback of the external NRES level. The value is read on the DIAG\_OUT pin and NRES\_ERR bit (bit 5 in the SAFETY\_STAT\_3 register)..

For both the ENDRV pin and the NRES pin, the logic read-back threshold level is typically 400 mV.

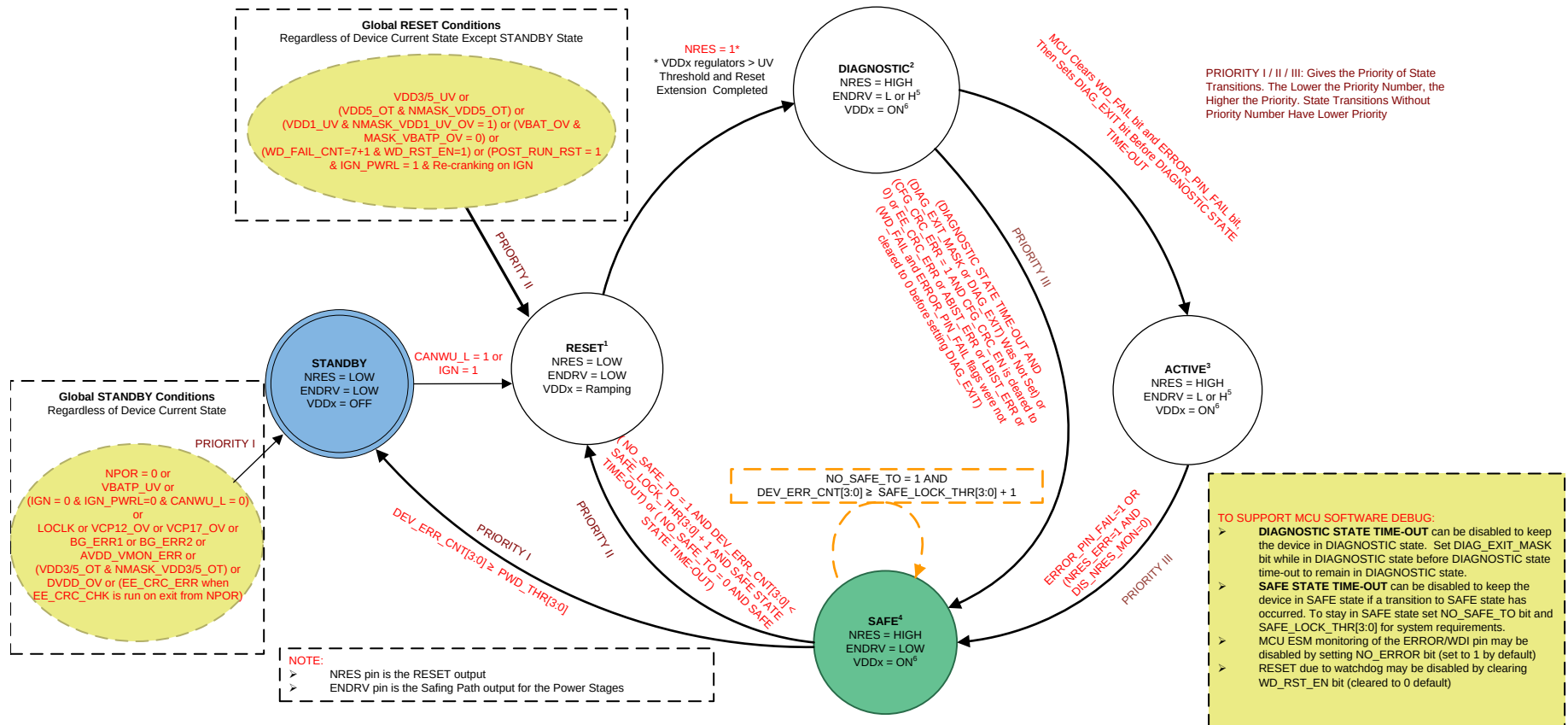
Figure 5-15 shows the timing-response diagram for the NRES and ENDRV pins to any VDDx undervoltage or overvoltage condition.



- (1) The signal deglitch time is defined for each undervoltage or overvoltage condition as given in [Section 4](#).
- (2) The NRES extension time is defined by the external resistor value as given in [Section 4](#).

**Figure 5-15. Timing-Response Diagram for NRES and ENDRV Pins to any VDDx Undervoltage or Overvoltage Condition**

### 5.4.19 Device Operating States



- (1) RESET State: SPI, Watchdog and MCU ESM are in reset; see [Section 5.4.21](#) section for conditions that prevent the wake up from the STANDBY state to the RESET state.
- (2) DIAGNOSTIC State: BIST (LBIST with ABIST) is initiated on the transition into the DIAGNOSTIC state. See [Section 5.4.22](#) for options to disable automatic BIST run, the DIAGNOSTIC state time-out and diagnostics the MCU may perform on safety functions. WD\_FAIL\_CNT reinitializes to 5 on transition into the DIAGNOSTIC state.
- (3) ACTIVE State: WD\_FAIL\_CNT reinitializes to 5 during transition into the ACTIVE state. During the ACTIVE state the MCU may perform diagnostics of some safety functions, see [Section 5.4.23](#) for more details.
- (4) SAFE State: DEV\_ERR\_CNT[3:0] increments on any transition to the SAFE state. See [Section 5.4.24](#) for details on SAFE state time-out.
- (5) The ENDRV pin level is dependent on the ENABLE\_DRV bit, WD\_FAIL\_CNT[2:0] counter value, and VDDx\_OV as shown in [Figure 5-14](#) in the DIAGNOSTIC and ACTIVE states.
- (6) The VDD5 and VSOUT1 regulators may be enabled or disabled in the DIAGNOSTIC, ACTIVE, and SAFE states.

**Figure 5-16. Device Controller State Diagram**



### 5.4.20 STANDBY State

The STANDBY state is the default state when the device is supplied by the VBATP and VBAT\_SAFING supplies. This state has the characteristics that follow:

- All regulators are disabled
- The NRES and ENDRV pins are low.
- The device transitions to the STANDBY state from any state because of the following:
  - Internal power-on reset event (NPOR = 0)
  - VBATP undervoltage event (VBATP\_UV)
  - Deglitched IGN = 0 and IGN\_PWRL = 0 (cleared IGN power-latch control bit) and CANWU\_L = 0
  - Loss-of-clock detection (LOCLK)
  - VDD3/5 overtemperature event (VDD3/5\_OT) while NMASK\_VDD3/5\_OT = 1
  - DVDD undervoltage event (DVDD\_UV)
  - DVDD overvoltage event (DVDD\_OV)
  - AVDD\_VMON overvoltage or undervoltage event (AVDD\_VMON\_ERR)
  - VCP12 overvoltage event (VCP12\_OV)
  - VCP17 overvoltage event (VCP17\_OV)
  - Error with band gaps: BG\_ERR1 or BG\_ERR2
  - EEPROM check fails during run after exit from NPOR event (EE\_CRC\_ERR = 1 when EE\_CRC\_CHK is run on exit from NPOR)
  - The device error count (DEV\_ERR\_CNT[3:0]) is greater than or equal to the programmed power-down threshold, PWD\_THR[3:0]

### 5.4.21 RESET State

The RESET state has the characteristics that follow:

- This state is entered from the STANDBY state after a wake-up request from ignition (IGN pin = high, deglitched IGN bit = 1) or CANWU pin (CANWU pin = high, deglitched and latched CANWU\_L bit = 1). The following conditions would prevent the transition from the STANDBY state to the RESET state even if a wake-up request occurred:
  - BG\_ERR1
  - BG\_ERR2
  - VCP17\_OV
  - VCP12\_OV
  - AVDD\_VMON\_ERR
  - EE\_CRC\_CHK fails
- This state is entered from the SAFE state after a SAFE state time-out occurs and the DEV\_ERR\_CNT[3:0] counter is less than the programmed SAFE\_LOCK\_THR[3:0] + 1. See [Section 5.4.24](#) for details on the SAFE state time-out duration which is set by the SAFE\_TO[2:0] and NO\_SAFE\_TO bits.
- The device transitions to the RESET state from any other state because of the following:
  - VDD3/5 undervoltage event (VDD3/5\_UV)
  - VDD5 overtemperature event (VDD5\_OT) when NMASK\_VDD5\_OT = 1
  - VDD1 undervoltage event (VDD1\_UV) when NMASK\_VDD1\_UV\_OV = 1 (not default)
  - VBATP overvoltage event (VBATP\_OV) when MASK\_VBATP\_OV = 0 (default)
  - Watchdog reset. A watchdog reset occurs after the watchdog fail counter (WD\_FAIL\_CNT[2:0]) has reached a value of 7 and another bad event occurs (7+1) which sets the WD\_FAIL flag when WD\_RST\_EN = 1 (not default)
  - POST\_RUN\_RST = 1 and IGN\_PWRL = 1 and a re crank (LOW followed by a valid HIGH) on IGN pin
- The VDDx regulators are powered on.

- The NRES and ENDRV pins are low.
- The SPI, watchdog, and MCU ESM are in reset.

#### 5.4.22 DIAGNOSTIC State

The DIAGNOSTIC state has the characteristics that follow:

- The DIAGNOSTIC state is entered from the RESET state after the VDDx regulators have ramped-up and the reset extension is complete
- The VDD5 (enabled by default) regulator can be disabled by the VDD5\_EN bit, and the VSOUT1 regulator can be enabled (disabled by default) by the VSOUT1\_EN bit.
- The NRES pin is HIGH.
- The state of the ENDRV pin is determined by the ENABLE\_DRV bit, WD\_FAIL\_CNT[2:0] counter value, and the overvoltage monitoring for the VDDx regulators (VDDx\_OV) as shown in [Figure 5-14](#).
- The watchdog and MCU error signal monitoring (ESM) functions can be configured and operated. The MCU ESM module does not cause a transition to the SAFE state from the DIAGNOSTIC state when an emulated failure on the ERROR/WDI pin is detected. This allows the MCU to run diagnostics on the MCU ESM and ERROR/WDI pin during the DIAGNOSTIC state.
- This state is where the MCU should perform all device self-tests and diagnostics (failures are induced to emulate internal failures and confirm detection).
- Upon entry of the DIAGNOSTIC state, the watchdog fail counter is reinitialized to 5.
- The BIST (LBIST with ABIST) is activated with the transition out of the RESET state into the DIAGNOSTIC including a power up event from the STANDBY state. This automatic BIST run can be disabled with the AUTO\_BIST\_DIS bit for cases when the RESET state was entered from the DIAGNOSTIC, ACTIVE, or SAFE state, but cannot be disabled when the RESET state was entered from the STANDBY state at power up.
- The BIST (LBIST with ABIST) is initiated on the transition to the DIAGNOSTIC state.
- During the DIAGNOSTIC state, the MCU can perform diagnostics of any safety function such as watchdog, MCU ESM, ERROR/WDI pin, DIAG\_MUX pin, and CRC on registers. Ti recommends running diagnostic checks at least every power-up cycle while in the DIAGNOSTIC state.

#### NOTE

**DIAGNOSTIC state time-out:** When the DIAGNOSTIC state is entered, if the DIAG\_EXIT\_MASK or DIAG\_EXIT bit is not set to 1 within 512 ms (typical), the DIAGNOSTIC state time-out interval expires, causing a transition to the SAFE state. This also sets both the ERROR\_PIN\_FAIL and WD\_FAIL bits in the SAFETY\_ERR\_STAT register and sets the mirror bits, MCU\_ERR and WD\_ERR, in the SAFETY\_STAT\_4 register. The device error count (DEV\_ERR\_CNT[3:0]) is incremented. Only the DIAG\_EXIT\_MASK or DIAG\_EXIT bit should be set in a single SPI write command to the SAFETY\_CHECK\_CTRL register. Setting the DIAG\_EXIT bit to 1 causes a transition to the ACTIVE state. Setting the DIAG\_EXIT\_MASK bit to 1 causes the device to remain in the DIAGNOSTIC state (only recommended for software debug).

#### NOTE

**DIAG\_EXIT\_MASK for software debug:** When the DIAG\_EXIT\_MASK bit is set to 1 before the DIAGNOSTIC state time-out interval expires, the device stays in the DIAGNOSTIC state until the bit is cleared. The DIAGNOSTIC state time-out timer remains free running in the background, but does not cause a state transition. When the DIAGNOSTIC state time-out interval has expired, the DIAG\_EXIT bit is set automatically (in addition to the DIAG\_EXIT\_MASK bit remaining set) and the device remains in the DIAGNOSTIC state. For a controlled transition to the ACTIVE state, TI recommends clearing the DIAG\_EXIT\_MASK bit and setting the DIAG\_EXIT bit with a single SPI write command to the SAFETY\_CHECK\_CTRL register. If both the DIAG\_EXIT\_MASK bit and DIAG\_EXIT bits are cleared at the same time, the device remains in the DIAGNOSTIC state until either the next DIAGNOSTIC state time-out interval expires causing a transition to the SAFE state or if the DIAG\_EXIT bit is set to 1, prior to the DIAGNOSTIC state time-out, transitioning the device to ACTIVE state.

#### NOTE

In the DIAGNOSTIC state the following considerations must be considered if a manual run of the LBIST is initiated by setting the LBIST\_EN bit to 1. Setting the LBIST\_EN bit to 1 clears the DIAG\_EXIT\_MASK bit to 0. If the DIAG\_EXIT\_MASK bit is being used to hold the device in the DIAGNOSTIC state for software debug, it must be set again to 1 after LBIST completion to stay in the DIAGNOSTIC state. The DIAGNOSTIC state time-out counter stops only during the running of LBIST. After the LBIST completes, the time-out counter continues from the last value. For a transition from the DIAGNOSTIC state to the ACTIVE state, the DIAG\_EXIT bit must be set to 1.

### 5.4.23 ACTIVE State

The ACTIVE state has the characteristics that follow:

- The device enters from the DIAGNOSTIC state after the MCU sets the DIAG\_EXIT bit after clearing the ERROR\_PIN\_FAIL and WD\_FAIL bits.

#### NOTE

While in the DIAGNOSTIC state, the MCU must clear by writing a 0 to the ERROR\_PIN\_FAIL bit and the WD\_FAIL bit in the SAFETY\_ERR\_STAT register before setting the DIAG\_EXIT bit. Clearing these bits also clears their mirror bits, MCU\_ERR and WD\_ERR. Otherwise, a transition to the SAFE state occurs.

- The NRES pin is high.
- The state of the ENDRV pin is determined by the ENABLE\_DRV bit, WD\_FAIL\_CNT[2:0] counter value, and the overvoltage monitoring for the VDDx regulators (VDDx\_OV) as shown in [Figure 5-14](#);
- The VDDx regulators are on, the VDD5 regulator can be enabled or disabled through the VDD5\_EN bit. The VSOUT1 regulator can be enabled or disabled through the VSOUT1\_EN bit.
- The WD\_FAIL\_CNT[2:0] counter reinitializes to 5 during a transition from the DIAGNOSTIC state to the ACTIVE state.
- The watchdog and MCU ESM monitoring functions are operated as configured but cannot be reconfigured.
- During the ACTIVE state, the MCU can perform diagnostics of some safety function such as watchdog, DIAG\_MUX pin, ABIST (approximately 300  $\mu$ s, ENDRV pin will be low), LBIST (approximately 21 ms, ENDRV pin will be low), and CRC on registers depending on the system safety requirements.

**NOTE**

In the ACTIVE state the following considerations must be considered if a manual run of the LBIST is initiated by setting the LBIST\_EN bit to 1. The LBIST should only be run in the ACTIVE state if the system-safety timing requirements can allow the total 21-ms BIST time and the ENDRV pin being low for the 21-ms.

See [Section 5.4.7](#) for additional system considerations if LBIST is run in the ACTIVE state.

**5.4.24 SAFE State**

The SAFE state has the characteristics that follow:

- The SAFE state is entered from:
  - The ACTIVE state by:
    - An error in the signal on the ERROR/WDI pin detected by the MCU ESM while enabled.. This transition is because of an error in the MCU and sets the ERROR\_PIN\_FAIL flag.
    - A detected read-back error on the NRES pin which sets the NRES\_ERR flag while DIS\_NRES\_MON is cleared to 0 (1 in default state).
  - The DIAGNOSTIC state by:
    - After a DIAGNOSTIC state time-out event happens before the DIAG\_EXIT\_MASK bit is set to 1, keeping the device in the DIAGNOSTIC state or before the DIAG\_EXIT bit is set to 1 transitioning the device to ACTIVE.
  - CFG\_CRC\_ERR = 1 AND CFG\_CRC\_EN is cleared to 0
  - An EE\_CRC\_ERR is detected in the DIAGNOSTIC state.
  - An ABIST\_ERR or LBIST\_ERR is detected in the DIAGNOSTIC state.
  - The WD\_FAIL and ERROR\_PIN\_FAIL flags were not cleared to 0 before setting the DIAG\_EXIT bit while exiting the DIAGNOSTIC state.
- Every transition to the SAFE state increments the device error count, DEV\_ERR\_CNT[3:0].
- The device stays in the SAFE state when the NO\_SAFE\_TO bit is set to 1 (default state) and DEV\_ERR\_CNT[3:0] = SAFE\_LOCK\_THR[3:0] + 1. This allows for programming the MCU without causing a reset and transition to the RESET state because of the SAFE state time-out.
- The NRES pin is high.
- The ENDRV pin is low.
- The VDDx regulators are on, the VDD5 regulator can be enabled or disabled with the VDD5\_EN bit. The VSOUT1 regulator can be enabled or disabled with the VSOUT1\_EN bit.

### NOTE

The SAFE state time-out and device configuration settings are used by the device state machine to determine what the device does after a transition to the SAFE state. Depending on the NO\_SAFE\_TO, PWD\_THR[3:0], SAFE\_LOCK\_THR[3:0], and DEV\_ERR\_CNT[3:0] bits, the device stays locked in the SAFE state, transitions to the RESET state, or transitions to STANDBY state. The SAFE state time-out duration is programmable through SAFE\_TO[2:0].

#### **NO\_SAFE\_TO = 1 (Default)**

- While DEV\_ERR\_CNT[3:0] < (SAFE\_LOCK\_THR[3:0] + 1) the time delay for the SAFE state time-out is programmed by the SAFE\_TO[2:0] bit. The delay is calculated by  $[(SAFE\_TO[2:0] \times 2) + 1] \times 22 \text{ ms}$ .
- The device remains locked in the SAFE state when DEV\_ERR\_CNT[3:0] ≥ SAFE\_LOCK\_THR[3:0] + 1.

#### **NO\_SAFE\_TO = 0**

- While DEV\_ERR\_CNT[3:0] < (SAFE\_LOCK\_THR[3:0] + 1) the time delay for the SAFE state time-out is programmed by the SAFE\_TO[2:0] bits. The delay is calculated by  $[(SAFE\_TO[2:0] \times 2) + 1] \times 22 \text{ ms}$ .
- When DEV\_ERR\_CNT[3:0] ≥ SAFE\_LOCK\_THR[3:0] + 1, the SAFE state time-out duration changes and the device transitions to the RESET state after approximately 680 ms.

If the PWD\_THR[3:0] threshold is used, the device transitions from the SAFE state to the STANDBY state when DEV\_ERR\_CNT[3:0] ≥ PWD\_THR[3:0]. This transition has higher priority (PRIORITY I) than the path from the SAFE state to the RESET state (PRIORITY II) so if PWD\_THR[3:0] = SAFE\_LOCK\_THR[3:0] + 1 the device transitions to the STANDBY state not the RESET state.

### 5.4.25 State Transition Priorities

For all global or possible double-state transitions, the following priorities hold true:

1. Priority I: all conditions for STANDBY state transition
2. Priority II: all conditions for RESET state transition
3. Priority III: all conditions for SAFE state transition

All other state transitions have a lower priority compared to any of the state transitions listed with priority numbers.

### 5.4.26 Power on Reset (NPOR)

The device goes through a power on reset (NPOR) which reinitializes all registers. The events that cause an NPOR are:

- Analog power on reset:
  - Loss-of-clock detection (LOCLK)
  - AVDD\_VMON overvoltage or undervoltage event (AVDD\_VMON\_ERR)
  - DVDD undervoltage event (DVDD\_UV)
  - DVDD overvoltage event (DVDD\_OV)

- Digital power on reset. These errors can cause a NPOR. If the detected fault duration is less than 6 ms, an NPOR may not occur. When the CANWU or IGN state is kept high, the device transitions to the RESET state because of the wake-up request. The registers on the post-BIST reinitialization list are reinitialized after BIST runs on the transition from the RESET state to the DIAGNOSTIC state (unless AUTO\_BIST\_DIS = 1, not default).
  - VBATP undervoltage event (VBATP\_UV)
  - VDD3/5 overtemperature event (VDD3/5\_OT) while NMASK\_VDD3/5\_OT = 1
  - AVDD undervoltage event (AVDD\_UV)
  - Error with the device VMON trim settings (VMON\_TRIM\_ERROR)
  - Error with band gaps: BG\_ERR1 or BG\_ERR2
  - VCP12 overvoltage event (VCP12\_OV)
  - VCP17 overvoltage event (VCP17\_OV)

## 5.5 Register Maps

### 5.5.1 Serial Peripheral Interface (SPI)

The primary communication between the device and the external the MCU is through a SPI bus which provides full-duplex communications in a master-slave configuration. The external MCU is always a SPI master, which sends command requests on the SDI pin and receives device responses on the SDO pin. The TPS65381A-Q1 device is always a SPI slave device, which receives command requests and sends responses (status, measured values) to the external MCU over the SDO line.

- The SPI is a 4-pin interface.
  - NCS—SPI chip select (active-low)
  - SCLK—SPI clock
  - SDI—SPI slave-in and master-out (SIMO)
  - SDO—SPI slave-out and master-in (SOMI, three-state output)
- The SPI frame size is 16 bits.
- Speed is up to 6 Mbit/s.
- Commands and data are shifted MSB first, LSB last.
- The SDI line is sampled on the falling edge of SCLK.
- The SDO line is shifted out on the rising edge of SCLK.

The SPI communication starts with the NCS falling edge, and ends with the NCS rising edge. The NCS high level keeps the SPI slave interface in the reset state, and the SDO output is in the tri-state.

#### 5.5.1.1 SPI Command Transfer Phase

Table 5-15 shows the transfer frame format of SPI data during a command (write or read command)..

**Table 5-15. SPI Command Transfer Phase**

| BIT      | D7   | D6   | D5   | D4   | D3   | D2   | D1   | D0     |
|----------|------|------|------|------|------|------|------|--------|
| FUNCTION | CMD6 | CMD5 | CMD4 | CMD3 | CMD2 | CMD1 | CMD0 | PARITY |

**CMD[6:0]** Register write (WR) or read (RD) command

**PARITY** Parity bit for 7-bit command field

The SPI does not support back-to-back SPI frame operation. After each SPI command or read access, the NCS pin must transition from low-to-high before the next SPI transfer can start. The minimum time ( $t_{hlcs}$ ) between two SPI commands during which the NCS pin must remain high is 788 ns.

#### 5.5.1.2 SPI Data-Transfer Phase

Table 5-16 shows the transfer frame format of SPI data during a write access.

**Table 5-16. SPI Data-Transfer Phase**

| BIT      | D7    | D6    | D5    | D4    | D3    | D2    | D1    | D0    |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|
| FUNCTION | DATA7 | DATA6 | DATA5 | DATA4 | DATA3 | DATA2 | DATA1 | DATA0 |

**DATA[7:0]** Data value for write access (8-bit)

The SPI does not support back-to-back SPI frame operation. After each SPI transfer, the NCS pin must go from low to high before the next SPI transfer can start. The minimum time ( $t_{hncs}$ ) between two SPI commands during which the NCS pin must remain high is 788 ns.

### 5.5.1.3 Device Status Flag Byte Response

Table 5-17 shows the response frame format of the SPI data status during a command (write or read access).

**Table 5-17. Device Status Flag Byte Response**

| BIT      | R7      | R6      | R5      | R4      | R3      | R2      | R1      | R0      |
|----------|---------|---------|---------|---------|---------|---------|---------|---------|
| FUNCTION | STAT[7] | STAT[6] | STAT[5] | STAT[4] | STAT[3] | STAT[2] | STAT[1] | STAT[0] |

**STAT[7]**

1

**STAT[6]**

0

**STAT[5]**

1

**STAT[4]**

0

**STAT[3]** SPI WR access (during previous SPI frame-command phase)

**STAT[2]** SPI SDO error (during previous SPI frame)

**STAT[1]**

0

**STAT[0]** SPI errors including truncated SPI frames, SPI transfers with more than 16 bits, SPI transfers with undefined commands or SPI transfers with incorrect command parity (during previous SPI frame)

The status bits sent during the current SPI command are reflecting the status of the previous SPI command.

#### NOTE

If a reset to the MCU is asserted during a SPI frame transfer (causing a truncated SPI frame), these SPI error status bits are not cleared, but maintain the status according to the truncated previous SPI frame until a SPI read access.

#### NOTE

The SPI SDO error bit, STAT[2], may be inadvertently set when the NCS pin is high, the SDO pin is high, and a falling edge occurs on the SPICLK pin. This combination occurs most often when the device is used in a SPI bus with multiple SPI slaves. If all three of these conditions are met, the SDO error flag is set to 1 in the second SPI flag byte response of the following SPI communication with the TPS65381A-Q1. The application software should mask out the SDO error flag if the device is used under these conditions. If a SPI SDO error is detected, the device accepts the SPI transfer because the detected error is on the output not the input for the SPI.

#### NOTE

For additional diagnostic coverage for SPI write transfers, the system software could perform a read of the register written and compare the returned value to the value that is expected after the write. Be aware some bits in some registers are not writable.



#### 5.5.1.4 Device SPI Data Response

Table 5-18 shows the response frame format of the SPI device data during a write or read access.

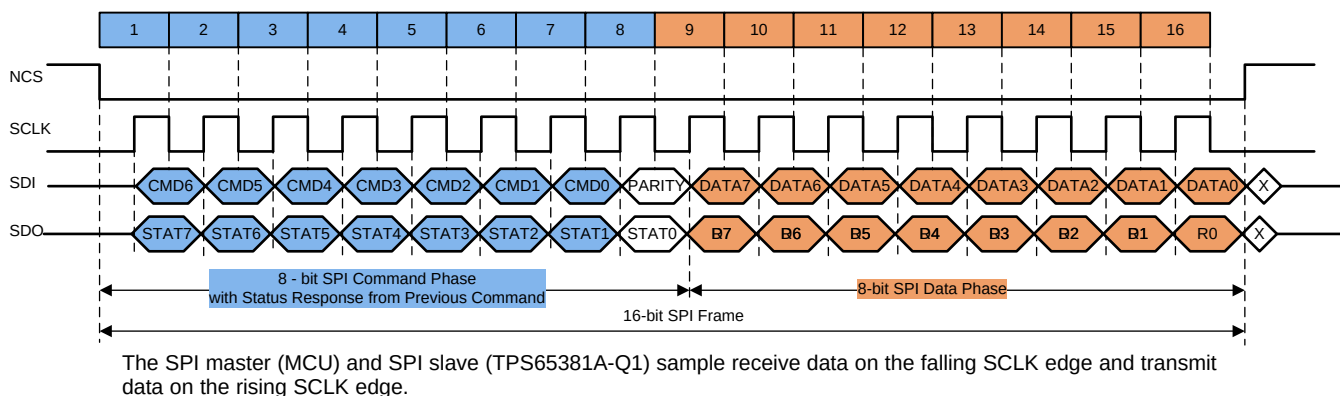
**Table 5-18. Device SPI Data Response**

| BIT      | R7 | R6 | R5 | R4 | R3 | R2 | R1 | R0 |
|----------|----|----|----|----|----|----|----|----|
| FUNCTION | R7 | R6 | R5 | R4 | R3 | R2 | R1 | R0 |

**R[7:0]** Internal register value. All unused bits are cleared to 0.

#### 5.5.1.5 SPI Frame Overview

Figure 5-17 shows an overview of a complete 16-bit SPI Frame:



**Figure 5-17. 16-Bit SPI Frame**

#### 5.5.2 SPI Register Write Access Lock (SW\_LOCK command)

The SW\_LOCK command protects the SPI registers against write update access through MCU control. When the SW\_LOCK command with data AAh is sent to the device, the listed registers are locked from updates through a write access. To unlock the SPI registers, the SW\_UNLOCK command with data 55h is sent to the device.

##### NOTE

The SW\_LOCK command is in addition to the automatic locking of specific SPI registers against write update access except while the device is in DIAGNOSTIC state. Please see the SPI Command Table and the register descriptions to determine if SW\_LOCK and automatic locking except in DIAGNOSTIC state apply to specific write access registers.

#### 5.5.3 SPI Registers (SPI Mapped Response)

The following sections list the SPI registers. For each SPI register, the bit names are given along with the initialized values (values after internal logic reset).

The values are initialized after each wake-up from the STANDBY state or after any other power-on reset (NPOR) event.

After a LBIST run is complete, including the LBIST run on the transition out of RESET state, the following functions and registers re-initialize:

- DEV\_STAT
- SAFETY\_STAT\_2
- SAFETY\_STAT\_4
- SAFETY\_STAT\_5 (but FSM[2:0] immediately updates to reflect the current device state)
- WD\_TOKEN\_VALUE



- WD\_STATUS
- SAFETY\_CHECK\_CTRL
- DIAG\_CFG\_CTRL
- DIAG\_MUX\_SEL

The initialized value of the reserved bits (RSV) is indicated, however some of these bits are used for internal device operation and the application software should mask them as they may not remain at their initialized value.

The following sections also list an explanation of each bit function.

**Table 5-19. SPI Command Table**

| 8-BIT HEX<br>COMMAND<br>CODE<br>(WITH<br>PARITY) | 7-BIT HEX<br>COMMAND<br>CODE<br>(WITHOUT<br>PARITY) | 7-BIT<br>BINARY<br>COMMAND<br>CODE<br>(WITHOUT<br>PARITY) | PARITY | WR SW<br>LOCK<br>PROTECT | REGISTER COMMAND NAME <sup>(1)</sup>                                         |
|--------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------------|--------|--------------------------|------------------------------------------------------------------------------|
| BDh                                              | 5Eh                                                 | 1011 110b                                                 | 1      | N/A                      | SW_LOCK with data AAh (to lock SPI WR access to listed registers)            |
| BBh                                              | 5Dh                                                 | 1011 101b                                                 | 1      | N/A                      | SW_UNLOCK with data 55h (to unlock SPI WR access to listed registers)        |
| 06h                                              | 03h                                                 | 0000 011b                                                 | 0      | N/A                      | RD_DEV_ID                                                                    |
| 0Ch                                              | 06h                                                 | 0000 110b                                                 | 0      | N/A                      | RD_DEV_REV                                                                   |
| B7h                                              | 5Bh                                                 | 1011 011b                                                 | 1      | YES                      | WR_DEV_CFG1 (SPI WR update can occur only in the DIAGNOSTIC state)           |
| AFh                                              | 57h                                                 | 1010 111b                                                 | 1      | N/A                      | RD_DEV_CFG1                                                                  |
| 95h                                              | 4Ah                                                 | 1001 010b                                                 | 1      | YES                      | WR_DEV_CFG2 (SPI WR update can occur only in the DIAGNOSTIC state)           |
| 48h                                              | 24h                                                 | 0100 100b                                                 | 0      | N/A                      | RD_DEV_CFG2                                                                  |
| 7Dh                                              | 3Eh                                                 | 0111 110b                                                 | 1      | NO                       | WR_CAN_STBY (only valid with data 00h)                                       |
| 24h                                              | 12h                                                 | 0010 010b                                                 | 0      | N/A                      | RD_SAFETY_STAT_1                                                             |
| C5h                                              | 62h                                                 | 1100 010b                                                 | 1      | N/A                      | RD_SAFETY_STAT_2                                                             |
| A3h                                              | 51h                                                 | 1010 001b                                                 | 1      | N/A                      | RD_SAFETY_STAT_3                                                             |
| A5h                                              | 52h                                                 | 1010 010b                                                 | 1      | N/A                      | RD_SAFETY_STAT_4                                                             |
| C0h                                              | 60h                                                 | 1100 000b                                                 | 0      | N/A                      | RD_SAFETY_STAT_5                                                             |
| 30h                                              | 18h                                                 | 0011 000b                                                 | 0      | N/A                      | RD_SAFETY_ERR_CFG                                                            |
| DBh                                              | 6Dh                                                 | 1101 101b                                                 | 1      | YES                      | WR_SAFETY_ERR_CFG (SPI WR update can occur only in the DIAGNOSTIC state)     |
| A9h                                              | 54h                                                 | 1010 100b                                                 | 1      | YES                      | WR_SAFETY_ERR_STAT (SPI WR update can occur only in the DIAGNOSTIC state)    |
| AAh                                              | 55h                                                 | 1010 101b                                                 | 0      | N/A                      | RD_SAFETY_ERR_STAT                                                           |
| 39h                                              | 1Ch                                                 | 0011 100b                                                 | 1      | N/A                      | RD_SAFETY_PWD_THR_CFG                                                        |
| 99h                                              | 4Ch                                                 | 1001 100b                                                 | 1      | YES                      | WR_SAFETY_PWD_THR_CFG (SPI WR update can occur only in the DIAGNOSTIC state) |
| 44h                                              | 22h                                                 | 0100 010b                                                 | 0      | N/A                      | RD_SAFETY_CHECK_CTRL                                                         |
| 93h                                              | 49h                                                 | 1001 001b                                                 | 1      | NO                       | WR_SAFETY_CHECK_CTRL                                                         |
| 3Ch                                              | 1Eh                                                 | 0011 110b                                                 | 0      | N/A                      | RD_SAFETY_BIST_CTRL                                                          |
| 9Fh                                              | 4Fh                                                 | 1001 111b                                                 | 1      | YES                      | WR_SAFETY_BIST_CTRL                                                          |
| 2Eh                                              | 17h                                                 | 0010 111b                                                 | 0      | N/A                      | RD_WD_WIN1_CFG                                                               |
| EDh                                              | 76h                                                 | 1110 110b                                                 | 1      | YES                      | WR_WD_WIN1_CFG (SPI WR update can occur only in the DIAGNOSTIC state)        |
| 05h                                              | 02h                                                 | 0000 010b                                                 | 1      | N/A                      | RD_WD_WIN2_CFG                                                               |
| 09h                                              | 04h                                                 | 0000 100b                                                 | 1      | YES                      | WR_WD_WIN2_CFG (SPI WR update can occur only in the DIAGNOSTIC state)        |

(1) All commands have even parity.

Table 5-19. SPI Command Table (continued)

| 8-BIT HEX<br>COMMAND<br>CODE<br>(WITH<br>PARITY) | 7-BIT HEX<br>COMMAND<br>CODE<br>(WITHOUT<br>PARITY) | 7-BIT<br>BINARY<br>COMMAND<br>CODE<br>(WITHOUT<br>PARITY) | PARITY | WR SW<br>LOCK<br>PROTECT | REGISTER COMMAND NAME <sup>(1)</sup>                                       |
|--------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------------|--------|--------------------------|----------------------------------------------------------------------------|
| 36h                                              | 1Bh                                                 | 0011 011b                                                 | 0      | N/A                      | RD_WD_TOKEN_VALUE                                                          |
| 4Eh                                              | 27h                                                 | 0100 111b                                                 | 0      | N/A                      | RD_WD_STATUS                                                               |
| E1h                                              | 70h                                                 | 1110 000b                                                 | 1      | NO                       | WR_WD_ANSWER                                                               |
| 11h                                              | 08h                                                 | 0001 000b                                                 | 1      | N/A                      | RD_DEV_STAT                                                                |
| 12h                                              | 09h                                                 | 0001 001b                                                 | 0      | N/A                      | RD_VMON_STAT_1                                                             |
| A6h                                              | 53h                                                 | 1010 011b                                                 | 0      | N/A                      | RD_VMON_STAT_2                                                             |
| 56h                                              | 2Bh                                                 | 0101 011b                                                 | 0      | N/A                      | RD_SENS_CTRL                                                               |
| 7Bh                                              | 3Dh                                                 | 0111 101b                                                 | 1      | N/A                      | WR_SENS_CTRL                                                               |
| 3Ah                                              | 1Dh                                                 | 0011 101b                                                 | 0      | N/A                      | RD_SAFETY_FUNC_CFG                                                         |
| 35h                                              | 1Ah                                                 | 0011 010b                                                 | 1      | YES                      | WR_SAFETY_FUNC_CFG (SPI WR update can occur only in the DIAGNOSTIC state)  |
| 5Ah                                              | 2Dh                                                 | 0101 101b                                                 | 0      | N/A                      | RD_SAFETY_CFG_CRC                                                          |
| 63h                                              | 31h                                                 | 0110 001b                                                 | 1      | YES                      | WR_SAFETY_CFG_CRC (SPI WR update can occur only in the DIAGNOSTIC state)   |
| DDh                                              | 6Eh                                                 | 1101 110b                                                 | 1      | N/A                      | RD_DIAG_CFG_CTRL                                                           |
| CCh                                              | 66h                                                 | 1100 110b                                                 | 0      | NO                       | WR_DIAG_CFG_CTRL                                                           |
| ACh                                              | 56h                                                 | 1010 110b                                                 | 0      | N/A                      | RD_DIAG_MUX_SEL                                                            |
| C9h                                              | 64h                                                 | 1100 100b                                                 | 1      | NO                       | WR_DIAG_MUX_SEL                                                            |
| D7h                                              | 6Bh                                                 | 1101 011b                                                 | 1      | N/A                      | RD_SAFETY_ERR_PWM_H                                                        |
| D8h                                              | 6Ch                                                 | 1101 100b                                                 | 0      | YES                      | WR_SAFETY_ERR_PWM_H (SPI WR update can occur only in the DIAGNOSTIC state) |
| 59h                                              | 2Ch                                                 | 0101 100b                                                 | 1      | N/A                      | RD_SAFETY_ERR_PWM_L                                                        |
| 7Eh                                              | 3Fh                                                 | 0111 111b                                                 | 0      | YES                      | WR_SAFETY_ERR_PWM_L (SPI WR update can occur only in the DIAGNOSTIC state) |
| 78h                                              | 3Ch                                                 | 0111 100b                                                 | 0      | N/A                      | RD_WD_TOKEN_FDBK                                                           |
| 77h                                              | 3Bh                                                 | 0111 011b                                                 | 1      | YES                      | WR_WD_TOKEN_FDBK (SPI WR update can occur only in the DIAGNOSTIC state)    |

### 5.5.3.1 Device Revision and ID

#### 5.5.3.1.1 DEV\_REV Register

Initialization source: NPOR

Controller access: Read only (RD\_DEV\_REV)

Figure 5-18. DEV\_REV Register

| D7     | D6     | D5     | D4     | D3     | D2     | D1     | D0     |
|--------|--------|--------|--------|--------|--------|--------|--------|
| REV[7] | REV[6] | REV[5] | REV[4] | REV[3] | REV[2] | REV[1] | REV[0] |
| 0b     | 0b     | 1b     | 1b     | 0b     | 0b     | 0b     | 0b     |

**D[7:0]**    **REV[7:0]:** Device Revision

- REV[3:0]: Device minor revision
- REV[7:4]: Device major revision

### 5.5.3.1.2 DEV\_ID Register

**Initialization source:** NPOR

**Controller access:** Read only (RD\_DEV\_ID)

**Figure 5-19. DEV\_ID Register**

| D7    | D6    | D5    | D4    | D3    | D2    | D1    | D0    |
|-------|-------|-------|-------|-------|-------|-------|-------|
| ID[7] | ID[6] | ID[5] | ID[4] | ID[3] | ID[2] | ID[1] | ID[0] |
| 0b    | 0b    | 0b    | 0b    | 0b    | 0b    | 0b    | 1b    |

**D[7:0]** ID[7:0]: Device ID

### 5.5.3.2 Device Status

#### 5.5.3.2.1 DEV\_STAT Register

**Initialization source:** NPOR, post LBIST reinitialization

**Controller access:** Read only (RD\_DEV\_STAT)

**Figure 5-20. DEV\_STAT Register**

| D7  | D6  | D5  | D4  | D3  | D2  | D1      | D0  |
|-----|-----|-----|-----|-----|-----|---------|-----|
| RSV | RSV | RSV | RSV | RSV | RSV | CANWU_L | IGN |
| 0b  | 0b  | 0b  | 0b  | 0b  | 0b  | X       | X   |

**D[7:2]** RSV

**D[1]** **CANWU\_L**: Latched CAN wake-up event

- The initialized value depends on whether a device wake-up event occurs through the CANWU or IGN pin.
- This bit clears to 0 when a device wake-up occurs through a CANWU, only a WR\_CAN\_STBY command, or any other global STANDBY condition

**D[0]** **IGN**: Deglitched IGN pin (7.5-ms to 22-ms deglitch time)

- The initialized value depends on whether a device wake-up event occurs through the CANWU or IGN pin. This bit follows the deglitched IGN signal, and therefore is only cleared to 0 when the deglitched IGN is low or by any other global STANDBY condition.

### 5.5.3.3 Device Configuration

#### 5.5.3.3.1 DEV\_CFG1 Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_DEV\_CFG1)

Write (WR\_DEV\_CFG1). Write update can only occur in the DIAGNOSTIC state. Write access locked through SW\_LOCK command.

**Figure 5-21. DEV\_CFG1 Register**

| D7          | D6               | D5  | D4  | D3  | D2  | D1  | D0  |
|-------------|------------------|-----|-----|-----|-----|-----|-----|
| VDD_3_5_SEL | NMASK_VDD1_UV_OV | RSV | RSV | RSV | RSV | RSV | RSV |
| X           | 0b               | 0b  | 0b  | 0b  | 0b  | 0b  | 0b  |

**D[7] VDD\_3\_5\_SEL:** Status bit of VDD3/VDD5 selection at power up

- SEL\_VDD3/5 input pin is sampled and latched at power up
  - 0b = 5-V setting (SEL\_VDD3/5 pin to ground)
  - 1b = 3.3-V setting (SEL\_VDD3/5 pin not connected)
  - Value in the RESET state depends on state of SEL\_VDD3/5 pin at first power up
- This bit is read only

**Note:** This bit is the same as the SAFETY\_FUNC\_CFG bit, D0)

**D[6] NMASK\_VDD1\_UV\_OV**

- Cleared to 0 by default:
  - Masked VDD1\_OV does not impact the ENDRV pin state
  - Masked VDD1\_UV does not impact the NRES pin state
- The default setting (0, masked) can be used in case the VDD1 regulator is not used in an application and the external power FET is not populated.

**Note:** If the VDD1 regulator is used in an application, TI recommends setting this bit to 1 when the device is in the DIAGNOSTIC state after the first start-up or power-up event.

**Note:** Even if this bit is set to 1, but the VDD1\_SENSE pin is externally floating, the pin is pulled up. The pullup condition is detected but the VDD1\_OV condition is masked and the ENDRV pin state is not impacted.

**D[5:0] RSV**

### 5.5.3.3.2 DEV\_CFG2 Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_DEV\_CFG2)

Write (WR\_DEV\_CFG2). Write update can only occur in the DIAGNOSTIC state. Write access locked through SW\_LOCK command.

**Figure 5-22. DEV\_CFG2 Register**

| D7              | D6            | D5            | D4           | D3  | D2  | D1  | D0  |
|-----------------|---------------|---------------|--------------|-----|-----|-----|-----|
| NMASK_VDD3/5_OT | NMASK_VDD5_OT | MASK_VBATP_OV | POST_RUN_RST | RSV | RSV | RSV | RSV |
| 1b              | 1b            | 0b            | 0b           | 0b  | 0b  | 0b  | 0b  |

**D[7] NMASK\_VDD3/5\_OT**

- When set to 1 (default), an overtemperature event on the VDD3/5 or VDD6 regulator disables the VDD3/5 regulator and the device goes to the STANDBY state. The VDD3/5\_OT flag sets in the SAFETY\_STAT\_1 register while an overtemperature event is detected.
- When cleared to 0, an overtemperature event on the VDD3/5 or VDD6 regulator disables the VDD3/5 regulator. When the VDD3/5 regulator reaches the UV level, the device goes to the RESET state. The VDD3/5\_OT flag is still set in the SAFETY\_STAT\_1 register while an overtemperature event is detected.

**D[6] NMASK\_VDD5\_OT**

- When set to 1 (default), an overtemperature event on the VDD5 regulator disables the VDD5 regulator and the device goes to the RESET state. The VDD5\_OT flag is set in the SAFETY\_STAT\_1 register while an overtemperature event is detected.
- When cleared to 0 the VDD5 overtemperature shutdown is disabled and the VDD5 regulator remains enabled. The VDD5\_OT flag is still set in the SAFETY\_STAT\_1 register while an overtemperature event is detected.

**D[5] MASK\_VBATP\_OV**

- Cleared to 0 by default.
- When set to 1, the VBATP\_OV bit is masked from the RESET condition.

**D[4] POST\_RUN\_RST:**

- Cleared to 0 per default.
- When set to 1, while using the IGN\_PWRL function, a recracking on the IGN pin causes the device to go to the RESET state.

**D[3:0] RSV** (bits are readable and writable in the DIAGNOSTIC state with no impact to device state or the ENDRV and NRES output)

## 5.5.4 Device Safety Status and Control Registers

### 5.5.4.1 VMON\_STAT\_1 Register

**Initialization source:** NPOR

**Controller access:** Read only (RD\_VMON\_STAT\_1)

**Figure 5-23. VMON\_STAT\_1 Register**

| D7       | D6       | D5       | D4       | D3       | D2            | D1      | D0      |
|----------|----------|----------|----------|----------|---------------|---------|---------|
| VBATP_OV | VBATP_UV | VCP17_OV | VCP12_OV | VCP12_UV | AVDD_VMON_ERR | BG_ERR2 | BG_ERR1 |
| 0b       | 0b       | 0b       | 0b       | 0b       | 0b            | 0b      | 0b      |

- D[7] VBATP\_OV:** VBATP overvoltage status bit
- Set to 1 when a VBATP overvoltage condition is detected
  - Cleared to 0 if an overvoltage condition is no longer present
- D[6] VBATP\_UV:** VBATP undervoltage status bit
- Set to 1 when a VBATP undervoltage condition is detected
  - Cleared to 0 if an undervoltage condition is no longer present
- D[5] VCP17\_OV:** VCP17 overvoltage status bit
- Set to 1 when a VCP17 overvoltage condition is detected
  - Cleared to 0 if an overvoltage condition is no longer present
- D[4] VCP12\_OV:** VCP12 overvoltage status bit
- Set to 1 when a VCP12 overvoltage condition is detected
  - Cleared to 0 if an overvoltage condition is no longer present
- D[3] VCP12\_UV:** VCP12 undervoltage status bit
- Set to 1 when a VCP12 undervoltage condition is detected
  - Cleared to 0 if an undervoltage condition is no longer present
- D[2] AVDD\_VMON\_ERR:** voltage-monitor power-supply power-good status
- Set to 1 when voltage-monitor power supply is not OK.
  - Cleared to 0 if an error condition is no longer present
- D[1] BG\_ERR2:** Reference band-gap 2 error
- Set to 1 when the voltage monitor is less than the main band gap
  - Cleared to 0 if an error condition is no longer present
- D[0] BG\_ERR1:** Reference band-gap 1 error
- Set to 1 when the voltage monitor is greater than the main band gap
  - Cleared to 0 if an error condition is no longer present

### 5.5.4.2 VMON\_STAT\_2 Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_VMON\_STAT\_2)

**Figure 5-24. VMON\_STAT\_2 Register**

| D7      | D6      | D5      | D4      | D3        | D2        | D1      | D0      |
|---------|---------|---------|---------|-----------|-----------|---------|---------|
| VDD6_OV | VDD6_UV | VDD5_OV | VDD5_UV | VDD3/5_OV | VDD3/5_UV | VDD1_OV | VDD1_UV |
| 0b      | 0b      | 0b      | 0b      | 0b        | 0b        | 0b      | 0b      |

**D[7] VDD6\_OV:** VDD6 overvoltage status bit

- Set to 1 when a VDD6 overvoltage condition is detected
- Cleared to 0 if an overvoltage condition is no longer present

**D[6] VDD6\_UV:** VDD6 undervoltage status bit

- Set to 1 when a VDD6 undervoltage condition is detected
- Cleared to 0 if an undervoltage condition is no longer present

**D[5] VDD5\_OV:** VDD5 overvoltage status bit

- Set to 1 when a VDD5 overvoltage condition is detected
- Cleared to 0 if an overvoltage condition is no longer present

**D[4] VDD5\_UV:** VDD5 undervoltage status bit

- Set to 1 when a VDD5 undervoltage condition is detected.
- Cleared to 0 if an undervoltage condition is no longer present

**Note:** This status bit reflects the undervoltage status even if the VDD5\_EN bit in the SENS\_CTRL register has been cleared to 0. If the VDD5 regulator is disabled, when the VDD5 regulator discharges and an undervoltage condition is detected, the VDD5\_UV bit is set to 1.

**D[3] VDD3/5\_OV:** VDD3/5 overvoltage status bit

- Set to 1 when a VDD3/5 overvoltage condition is detected
- Cleared to 0 if an overvoltage condition is no longer present

**D[2] VDD3/5\_UV:** VDD3/5 undervoltage status bit

- Set to 1 when a VDD3/5 undervoltage condition is detected
- Cleared to 0 if an undervoltage condition is no longer present

**D[1] VDD1\_OV:** VDD1 overvoltage status bit

- Set to 1 when a VDD1 overvoltage condition is detected
- Cleared to 0 if an overvoltage condition is no longer present

**D[0] VDD1\_UV:** VDD1 undervoltage status bit

- Set to 1 when a VDD1 undervoltage condition is detected
- Cleared to 0 if an undervoltage condition is no longer present

### 5.5.4.3 SAFETY\_STAT\_1 Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_SAFETY\_STAT\_1)

**Figure 5-25. SAFETY\_STAT\_1 Register**

| D7        | D6          | D5        | D4        | D3  | D2        | D1      | D0         |
|-----------|-------------|-----------|-----------|-----|-----------|---------|------------|
| VDD5_ILIM | VDD3/5_ILIM | VSOUT1_UV | VSOUT1_OV | RSV | VSOUT1_OT | VDD5_OT | VDD_3_5_OT |
| 0b        | 0b          | 0b        | 0b        | 0b  | 0b        | 0b      | 0b         |

**D[7] VDD5\_ILIM:** VDD5 current-limit status bit

- Set to 1 when a VDD5 current-limit condition is exceeded
- Cleared to 0 if a current-limit condition is no longer present

**Note:** This status bit is valid only when the VDD5\_EN bit in SENS\_CTRL register is set to 1. When the VDD5\_EN bit is cleared to 0, this bit will be 1.

**D[6] VDD3/5\_ILIM:** VDD3 current-limit status bit

- Set to 1 when a VDD3 current-limit condition is exceeded
- Cleared to 0 if a current-limit condition is no longer present

**D[5] VSOUT1\_UV:** Sensor-supply undervoltage status bit

- Set to 1 when a VSOUT1 undervoltage condition is detected
- Cleared to 0 if an undervoltage condition is no longer present

**D[4] VSOUT1\_OV:** Sensor-supply overvoltage status bit

- Set to 1 when a VSOUT1 overvoltage condition is detected
- Cleared to 0 if an overvoltage condition is no longer present

**D[3] RSV**

**D[2] VSOUT1\_OT:** Sensor-supply overtemperature status bit

- Set to 1 when the VSOUT1 overtemperature condition is exceeded. This bit keeps the VSOUT1 regulator disabled as long as this bit is set.
- Cleared to 0 if an overtemperature condition is no longer present

**D[1] VDD5\_OT:** VDD5 overtemperature status bit

- Set to 1 when the VDD5 overtemperature condition is exceeded. When the NMASK\_VDD5\_OT bit is set 1, an overtemperature event disables the VDD5 regulator and clears the VDD5\_EN bit to 0 (SENS\_CTRL register). When the NMASK\_VDD5\_OT bit is 0, an overtemperature event sets the VDD5\_OT bit to 1 but no other device action is taken.
- Cleared to 0 if an overtemperature condition is no longer present

**D[0] VDD\_3\_5\_OT:** VDD3/5 overtemperature status bit

- Set to 1 when the VDD3/5 overtemperature condition is exceeded. This bit keeps VDD3/5 regulator disabled as long as this bit is set to 1.
- Cleared to 0 if an overtemperature condition is no longer present



#### 5.5.4.4 SAFETY\_STAT\_2 Register

**Initialization source:** NPOR, post LBIST reinitialization

**Controller access:** Read only (RD\_SAFETY\_STAT\_2)

**Figure 5-26. SAFETY\_STAT\_2 Register**

| D7  | D6  | D5          | D4         | D3  | D2                 | D1                 | D0                 |
|-----|-----|-------------|------------|-----|--------------------|--------------------|--------------------|
| RSV | RSV | CFG_CRC_ERR | EE_CRC_ERR | RSV | WD_FAIL_CNT<br>[2] | WD_FAIL_CNT<br>[1] | WD_FAIL_CNT<br>[0] |
| 0b  | 0b  | 0b          | 0b         | 0b  | 1b                 | 0b                 | 1b                 |

D[7:6] RSV

**D[5] CFG\_CRC\_ERR:** CRC error status bit for the safety configuration registers

- Safety configuration registers are protected by CRC8.
- This bit is set to 1 when the calculated CRC8 value for the safety configuration registers does not match the expected CRC8 value stored in the SAFETY\_CFG register.
- Cleared to 0 when a CRC8 mismatch is no longer present.
- Cleared to 0 when the EEPROM CRC performs without error (regardless of CFG\_CRC check result)

**D[4] EE\_CRC\_ERR:** EPROM CRC error status bit

- EEPROM content is protected by CRC8.
- This bit is set to 1 when the calculated CRC8 value does not match the expected CRC8 value stored in the EEPROM DFT register. When this bit is set to 1 and device is in the DIAGNOSTIC state, the device transitions to the SAFE state.
- Cleared to 0 when a CRC8 mismatch is no longer present.

D[3] RSV

**D[2:0] WD\_FAIL\_CNT[2:0]:** watchdog fail counter

- The default value is 5, and is initialized to this value upon entering the DIAGNOSTIC and ACTIVE state
- Watchdog fail counter increments every time the device watchdog detects a bad or time-out event and decrements each time a good event is received.
- Watchdog fail counter must decrease below 5 to enable the ENDRV pin.
- Watchdog fail is detected on the next bad or time-out event after the watchdog fail counter reached the count of 7 (that is 7+1) while the WD\_RST\_EN bit is set to 1. The WD\_FAIL status bit is set to 1 in the SAFETY\_ERR\_STAT register (setting the WD\_FAIL bit to 1 in the SAFETY\_ERR\_STAT register).

### 5.5.4.5 SAFETY\_STAT\_3 Register

**Initialization source:** NPOR

**Controller access:** Read only (RD\_SAFETY\_STAT\_3)

**Figure 5-27. SAFETY\_STAT\_3 Register**

| D7  | D6  | D5       | D4        | D3        | D2        | D1        | D0        |
|-----|-----|----------|-----------|-----------|-----------|-----------|-----------|
| RSV | RSV | NRES_ERR | LBIST_ERR | ABIST_ERR | ABIST_ERR | LBIST_RUN | ABIST_RUN |
| 0b  | 0b  | 0b       | 0b        | 0b        | 0b        | 0b        | 0b        |

D[7:6] RSV

**D[5] NRES\_ERR:** Reset error input status

- This bit is set to 1 when a mismatch between the NRES pin output HIGH and the NRES pin input readback LOW is detected, regardless of the value of the DIS\_RES\_MON bit. Depending on the external RC loading of this pin and the timing to read this bit, it may be set to 1 briefly if the external RC delay slows a change in level that is longer than the internal deglitch time (120  $\mu$ s typical).
- Cleared to 0 if no failure is present anymore.
- The DIS\_NRES\_MON bit in the SAFETY\_FUNC\_CFG register determines if this error causes a state transition from the ACTIVE state to the SAFE state.

**D[4] LBIST\_ERR:** Logic BIST (LBIST) error-status bit

- This bit is set to 1 when the LBIST fails
- Cleared to 0 after a LBIST run is complete without failure
- Only valid when the LBIST\_RUN bit is 0

**D[3] ABIST\_ERR:** Analog BIST (ABIST) error-status bit

- This bit is set to 1 when the ABIST fails. If this bit is set to 1 and the device is in the DIAGNOSTIC state, the device transitions to the SAFE state.
- Cleared to 0 after a ABIST run is complete without failure
- Only valid when the ABIST\_RUN bit is 0 (ABIST is not running)

**D[2] ABIST\_ERR:** Analog BIST (ABIST) error-status bit (identical to D3)

- This bit is set to 1 when the ABIST fails. If this bit is set to 1 and device is in the DIAGNOSTIC state, the device transitions to the SAFE state.
- Cleared to 0 after a ABIST run is complete without failure
- Only valid when the ABIST\_RUN bit is 0 (ABIST is not running)

**D[1] LBIST\_RUN:** Logic BIST (LBIST) run status bit

- This bit is set to 1 when a LBIST is running.
- Cleared to 0 when the LBIST is not running.

**D[0] ABIST\_RUN:** Analog BIST (ABIST) run status bit

- This bit is set to 1 when the ABIST is running.
- Cleared to 0 when the ABIST is not running.

#### 5.5.4.6 SAFETY\_STAT\_4 Register

**Initialization source:** NPOR, post LBIST reinitialization

**Controller access:** Read only (RD\_SAFETY\_STAT\_4)

**Figure 5-28. SAFETY\_STAT\_4 Register**

| D7         | D6         | D5    | D4  | D3      | D2     | D1        | D0            |
|------------|------------|-------|-----|---------|--------|-----------|---------------|
| SPI_ERR[1] | SPI_ERR[0] | LOCLK | RSV | MCU_ERR | WD_ERR | ENDRV_ERR | TRIM_ERR_VMON |
| 0b         | 0b         | 0b    | 0b  | 0b      | 0b     | 0b        | 0b            |

**D[7:6] SPI\_ERR[1:0]:** SPI error-status bits

00b = No error

01b = SPI SDO error (mismatch on SDO output)

If both a SPI SDO error and another SPI error occur during the same SPI frame, 01b is shown in the SPI\_ERR[1:0] bit because the SPI SDO error has priority.

10b = Reserved

11b = SPI errors including truncated SPI frames, SPI transfers with more than 16 bits, SPI transfers with undefined commands or SPI transfers with incorrect command parity

- Cleared to 0 after a SPI read access or any SPI frame with no errors.

**Note:** If a reset to the MCU is asserted during a SPI frame transfer (causing a truncated SPI frame), these SPI error status bits are not cleared, but maintain the status according to the truncated previous SPI frame until SPI read access

**D[5] LOCLK:** Loss of clock-detection status bit

- Set when a loss-of-clock failure is detected and also set after the ABIST is complete
- Cleared to 0 after internal NPOR and clear on read (after ABIST)

**D[4] RSV**

**D[3] MCU\_ERR:** MCU error signal monitor (MCU ESM) status bit

- This bit is set to 1 when the MCU ESM module detects an error on the ERROR/WDI pin while MCU ESM monitoring is enabled.
- This bit mirrors the ERROR\_PIN\_FAIL bit in the SAFETY\_ERR\_STAT register

**D[2] WD\_ERR:** Watchdog error-status bit

- This bit is set to 1 on the next bad or time-out event when the WD\_FAIL\_CNT[2:0] counter reaches a count of 7 (that is 7+1) when the WD\_RST\_EN bit (bit 3 in the SAFETY\_FUNC\_CFG) is set to 1. Also set to 1 when the DIAGNOSTIC state time-out occurs.
- This bit mirrors the WD\_FAIL bit in the SAFETY\_ERR\_STAT register

**D[1] ENDRV\_ERR:** Enable driver error

- This bit is set to 1 when a mismatch between the ENDRV pin output and the ENDRV input feedback is detected. Depending on the external RC loading of this pin and the timing to read this bit, it may be set to 1 briefly if the external RC delay slows a change in level that is longer than the internal deglitch time (32  $\mu$ s typical).
- Cleared to 0 if the failure is no longer present

**D[0] TRIM\_ERR\_VMON:** VMON trimming error-status bit

- This bit is set to 1 when mismatch voltage-monitor trim error is detected.
- Cleared to 0 after an internal NPOR and if failure is not present anymore.

### 5.5.4.7 SAFETY\_STAT\_5 Register

**Initialization source:** POR, post LBIST reinitialization

**Controller access:** Read only (RD\_SAFETY\_STAT\_5)

**Figure 5-29. SAFETY\_STAT\_5 Register**

| D7  | D6  | D5  | D4  | D3  | D2     | D1     | D0     |
|-----|-----|-----|-----|-----|--------|--------|--------|
| RSV | RSV | RSV | RSV | RSV | FSM[2] | FSM[1] | FSM[0] |
| 0b  | 0b  | 0b  | 0b  | 0b  | 0b     | 1b     | 1b     |

**D[2:0] FSM[2:0]:** Current device state

- Reflects the current device state (the bits will immediately update to reflect the current device state after an NPOR or post LBIST reinitialization)
  - STANDBY state: 00h
  - RESET state: 03h
  - DIAGNOSTIC state: 07h
  - ACTIVE state: 05h
  - SAFE state: 04h

### 5.5.4.8 SAFETY\_ERR\_CFG Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_SAFETY\_ERR\_CFG)

Write (WR\_SAFETY\_ERR\_CFG). Write update can only occur in the DIAGNOSTIC state. Write access locked through SW\_LOCK command.

**Figure 5-30. Register**

| D7          | D6          | D5          | D4                 | D3                 | D2                 | D1                 | D0       |
|-------------|-------------|-------------|--------------------|--------------------|--------------------|--------------------|----------|
| SAFE_TO [2] | SAFE_TO [1] | SAFE_TO [0] | SAFE_LOCK_T HR [3] | SAFE_LOCK_T HR [2] | SAFE_LOCK_T HR [1] | SAFE_LOCK_T HR [0] | CFG_LOCK |
| 0b          | 0b          | 0b          | 0b                 | 0b                 | 0b                 | 0b                 | 0b       |

**D[7:5] SAFE\_TO[2:0]:** SAFE state time-out settings

- Duration of the SAFE state is time-limited to protect against potential MCU *locked* state.
- Time-out duration =  $(2 \times \text{SAFE\_TO}[2:0] + 1) \times 22 \text{ ms}$
- Minimum duration is 22 ms
- Maximum duration is 330 ms
- 22-ms time reference has 5% accuracy coming from 4-MHz internal oscillator)

**D[4:1] SAFE\_LOCK\_THR[3:0]**

- Sets the corresponding device DEV\_ERR\_CNT[3:0] threshold at which device remains in the SAFE state regardless of SAFE state time-out event
- When the NO\_SAFE\_TO bit (SAFETY\_FUNC\_CFG register, bit 7) is set to 1:
  - While  $\text{DEV\_ERR\_CNT}[3:0] < \text{SAFE\_LOCK\_THR}[3:0] + 1$ , SAFE state time-out transition time from the SAFE-to-RESET state is controlled through the SAFE\_TO[2:0] bit settings. SAFE state time-out duration is calculated  $(\text{SAFE\_TO}[2:0] \times 2 + 1) \times 22 \text{ ms}$
  - Device remains *locked* in the SAFE state when the DEV\_ERR\_CNT[3:0] counter reaches  $\text{SAFE\_LOCK\_THR}[3:0] + 1$  value.
- When the NO\_SAFE\_TO bit (SAFETY\_FUNC\_CFG register, bit 7) is cleared to 0:
  - While  $\text{DEV\_ERR\_CNT}[3:0] < \text{SAFE\_LOCK\_THR}[3:0] + 1$ , time-out transition time from the SAFE-to-RESET state is controlled through the SAFE\_TO[2:0] bit settings. Time-delay duration is calculated  $(\text{SAFE\_TO}[2:0] \times 2 + 1) \times 22 \text{ ms}$
  - When the DEV\_ERR\_CNT[3:0] counter reaches  $\text{SAFE\_LOCK\_THR}[3:0] + 1$  value, the device transitions to the RESET state after 680 ms.
- Intended to support software debug and development and is NOT recommended for normal functional operation.
- The 0000b setting is the default setting, and has same effect as the 1111b setting. Both settings give the minimum threshold.

**D[0] CFG\_LOCK**

- Register lock access control
- When set to 1, the register content cannot be updated by SPI WR access.

### 5.5.4.9 SAFETY\_BIST\_CTRL Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_SAFETY\_BIST\_CTRL)

Write (WR\_SAFETY\_BIST\_CTRL). Write access locked through SW\_LOCK command.

**Figure 5-31. SAFETY\_BIST\_CTRL Register**

| D7                  | D6                  | D5                | D4         | D3  | D2       | D1       | D0       |
|---------------------|---------------------|-------------------|------------|-----|----------|----------|----------|
| BIST_DEG_CN<br>T[1] | BIST_DEG_CN<br>T[0] | AUTO_BIST_DI<br>S | EE_CRC_CHK | RSV | LBIST_EN | ABIST_EN | ABIST_EN |
| 0b                  | 0b                  | 0b                | 0b         | 0b  | 0b       | 0b       | 0b       |

**D[7:6] BIST\_DEG\_CNT[1:0]:** Deglitch filter duration setting during an active ABIST

- This bit controls the deglitch filter duration for every safety monitored voltage.
- Resolution is 15  $\mu$ s (with the minimum setting at 15  $\mu$ s and the maximum setting at 60  $\mu$ s):  $\text{bist\_deglitch} = (\text{BIST\_DEG\_CNT}[1:0] + 1) \times 15 \mu\text{s}$
- 15- $\mu$ s time reference has 5% accuracy coming from 4-MHz internal oscillator.
- When the ABIST is run in the ACTIVE state, TI recommends to set this to the maximum deglitch time

**D[5] AUTO\_BIST\_DIS**

- This bit controls the automatic BIST run on the transition from the RESET to the DIAGNOSTIC state ONLY when the device enters the RESET state from the DIAGNOSTIC, ACTIVE, or SAFE state.
- When set to 1, automatic BIST run is, except for the automatic BIST run on power up from the STANDBY state

**D[4] EE\_CRC\_CHK:** Recalculate EEPROM CRC8

- This bit controls the EEPROM CRC8 check function
- When set to 1, the EEPROM content is reloaded and CRC8 re-calculated and compared against expected value stored in EEPROM DFT register.

**Note:** With every power-up event, EEPROM content is reloaded and its CRC8 recalculated.

- The self-test status is checked through bit 4 in the SAFETY\_STAT\_2 register.

**D[3] RSV,** readable and writable without effect

**D[2] LBIST\_EN:** Enables LBIST run

- This bit controls the LBIST run (which also runs the ABIST)
- The self-test status is monitored through the D1 and D4 bits in the SAFETY\_STAT\_3 register.
- The LBIST\_EN bit clears the DIAG\_EXIT\_MASK bit to 0. The DIAGNOSTIC state time-out counter only stops during the running of the LBIST. After the LBIST is complete, the time-out counter continues from the last value. To stay in the DIAGNOSTIC state, the DIAG\_EXIT\_MASK bit must be set to 1 after LBIST completion. For a transition from the DIAGNOSTIC state to the ACTIVE state, the DIAG\_EXIT bit must be set to 1.

**D[1] ABIST\_EN:** Enable ABIST run (same as D[0])

- This bit controls the analog UV,OV and LOC BIST run.
- The self-test status is monitored through the D0, D2, and D3 bits in the SAFETY\_STAT\_3 register, and the D5 bit in the SAFETY\_STAT4 register.

**D[0] ABIST\_EN:** Enable analog BIST run (same as D[1])

- The bit controls the analog UV, OV, and LOC BIST run.
- The self-test status is monitored through the D0, D2, and D3 bits in the SAFETY\_STAT\_3 register, and the D5 bit in the SAFETY\_STAT4 register.

### 5.5.4.10 SAFETY\_CHECK\_CTRL Register

**Initialization source:** NPOR, post LBIST reinitialization

**Controller access:** Read (RD\_SAFETY\_CHECK\_CTRL)

Write (WR\_SAFETY\_CHECK\_CTRL). .

**Figure 5-32. SAFETY\_CHECK\_CTRL Register**

| D7         | D6  | D5         | D4  | D3  | D2       | D1             | D0        |
|------------|-----|------------|-----|-----|----------|----------------|-----------|
| CFG_CRC_EN | RSV | ENABLE_DRV | RSV | RSV | NO_ERROR | DIAG_EXIT_MASK | DIAG_EXIT |
| 0b         | 0b  | 0b         | 1b  | 0b  | 1b       | 0b             | 0b        |

**D[7] CFG\_CRC\_EN**

- This bit controls the enabling of CRC8 protection for the device configuration registers.
- When set to 1, the CRC8 is calculated for all device configuration registers and compared with the CRC8 value stored in the SAFETY\_CFG\_CRC register.
- TI recommends to first set the desired device configuration, followed by updating the SAFETY\_CFG\_CRC register before setting this bit to 1.
- The following registers are protected:
  - SAFETY\_FUNC\_CFG register
  - DEV\_REV (device revision) register
  - SAFETY\_PWD\_THR\_CFG register
  - SAFETY\_ERR\_CFG register
  - WD\_TOKEN\_CFG register
  - WD\_WIN1\_CFG register
  - WD\_WIN2\_CFG register
  - SAFETY\_ERR\_PWM\_L register
  - DEV\_CFG2 register
  - DEV\_CFG1 register (only the D6 bit)

D[6] RSV, readable and writeable with no impact to device state or the ENDRV, and NRES output

**D[5] ENABLE\_DRV**

- Controls the enabling of the ENDRV output
- In addition to setting this bit to 1, the watchdog fail counter must be decremented below the default count value of 5 to enable the ENDRV output.

D[4:3] RSV, readable and writeable with no impact to device state or the ENDRV, and NRES output

**D[2] NO\_ERROR**

- This bit enables MCU ESM monitoring of the ERROR/WDI pin. When enabled the MCU ESM transitions the device from the ACTIVE state to the SAFE state when an error is detected.
  - 0b = MCU ESM is enabled and the ERROR/WDI pin is monitored. A detected failure in the ACTIVE state causes a transition to the SAFE state, a detected failure in the DIAGNOSTIC state does not cause a transition to the SAFE state.
  - 1b = MCU ESM is not enabled and the ERROR/WDI pin is not monitored and a failure in the ACTIVE state does not cause a transition to the SAFE state.
- If a failure is detected when NO\_ERROR = 0 (MCU ESM is enabled).
  - The ERROR\_PIN\_FAIL status bit in the SAFETY\_ERR\_STAT register is set
  - The MCU\_ERR status bit in the SAFETY\_STAT\_4 register is set

**D[1] DIAG\_EXIT\_MASK**

- Controls the exit from the DIAGNOSTIC state
- When set to 1, exit from the DIAGNOSTIC state is disabled regardless if a DIAGNOSTIC state time-out event occurs or if the DIAG\_EXIT bit is set.
- This feature is only recommended for software debug and development and must not be activated in functional mode.

**D[0] DIAG\_EXIT**

- Controls exit from the DIAGNOSTIC state to the ACTIVE state
- When set to 1 and the DIAG\_EXIT\_MASK bit is 0, the device transitions from the DIAGNOSTIC to the ACTIVE state.

#### 5.5.4.11 SAFETY\_FUNC\_CFG Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_SAFETY\_FUNC\_CFG)

Write (WR\_SAFETY\_FUNC\_CFG). Write update can only occur in the DIAGNOSTIC state. Write access locked through SW\_LOCK command.

**Figure 5-33. SAFETY\_FUNC\_CFG Register**

| D7         | D6        | D5     | D4       | D3        | D2           | D1  | D0          |
|------------|-----------|--------|----------|-----------|--------------|-----|-------------|
| NO_SAFE_TO | ERROR_CFG | WD_CFG | IGN_PWRL | WD_RST_EN | DIS_NRES_MON | RSV | VDD_3_5_SEL |
| 1b         | 0b        | 0b     | 0b       | 0b        | 1b           | 0b  | X           |

**D[7] NO\_SAFE\_TO**

- Controls the enabling and disabling of the SAFE state time-out function
  - When set to 1: The SAFE state time-out is disabled. The device remains *locked* in the SAFE state when the DEV\_ERR\_CNT[3:0] counter reaches the SAFE\_LOCK\_THR[3:0] + 1 value.
  - When cleared to 0: The SAFE state time-out is enabled. The device transitions to the RESET state after 680 ms when the DEV\_ERR\_CNT[3:0] counter reaches the SAFE\_LOCK\_THR[3:0] + 1 value.

**D[6] ERROR\_CFG: MCU ESM configuration bit**

- When cleared to 0: PWM Mode is selected (can be used as an external clock monitor). The expected ERROR/WDI pin LOW and HIGH durations are controlled by the SAFETY\_ERR\_PWM\_H and SAFETY\_ERR\_PWM\_L registers (see [Section 5.5.4.14](#) and [Section 5.5.4.14](#), respectively).
- When set to 1: The TMS570 mode is selected. The ERROR pin low-duration threshold is set by the SAFETY\_ERR\_PWM\_L register.
- Use the NO\_ERROR bit in the SAFETY\_CHECK\_CTRL register to enable the MCU ESM function

**D[5] WD\_CFG: Watchdog function configuration bit**

- When cleared to 0: Trigger mode (default) – watchdog trigger input through the ERROR/WDI pin
- When set to 1: Q&A mode – watchdog answers input through SPI

**D[4] IGN\_PWRL: Ignition-power latch control bit**

- Controls the enabling of the ignition-power latch
  - Note:** This bit can only be changed when the device is in the DIAGNOSTIC state
  - When cleared to 0: With the IGN pin LOW, the device enters the STANDBY state. Cleared by a CANWU event
  - When set to 1: The IGN pin can be pulled LOW, but the device remains powered up.

**D[3] WD\_RST\_EN**

- 1b = Enables a transition to the RESET state when a Watchdog failure is detected (the WD\_FAIL\_CNT[2:0] counter reaches the count of 7+1).
- 0b (default) = Disables a transition to the RESET state when watchdog failure events are detected (the WD\_FAIL\_CNT[2:0] counter reaches the count of 7 + 1).

**D[2] DIS\_NRES\_MON**

- When cleared to 0: In the ACTIVE state, a difference between the read-back level on the NRES pin and the NRES pin output driver state causes a transition to the SAFE state and the NRES\_ERR bit is set.
- When set to 1 (default state): State transition because of a difference between the read-back NRES pin level and the NRES driver state is disabled. (default state) **Note:** The NRES\_ERR bit is still set if a difference between the read-back NRES pin level and the NRES driver state is detected.

**D[1] RSV, readable and writeable in the DIAGNOSTIC state with no impact to the device state or the ENDRV and NRES output**

**D[0] VDD\_3\_5\_SEL: Status bit of VDD3/VDD5 selection at power up**

- The SEL\_VDD3/5 input pin is sampled and latched at power up
  - 0b = 5-V setting (pin SEL\_VDD3/5 connected to ground)
  - 1b = 3.3-V setting (the SEL\_VDD3/5 pin is not connected)
  - Value in the RESET state depends on the state of the SEL\_VDD3/5 pin at first power up
- This bit is read only
  - Note:** This bit is the same as the DEV\_CFG1 bit, D7

#### 5.5.4.12 SAFETY\_ERR\_STAT Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_SAFETY\_ERR\_STAT)

Write (WR\_SAFETY\_ERR\_STAT). Write update can only occur in the DIAGNOSTIC state. Write access locked through SW\_LOCK command.

**Figure 5-34. SAFETY\_ERR\_STAT Register**

| D7  | D6  | D5             | D4      | D3             | D2             | D1             | D0             |
|-----|-----|----------------|---------|----------------|----------------|----------------|----------------|
| RSV | RSV | ERROR_PIN_FAIL | WD_FAIL | DEV_ERR_CNT[3] | DEV_ERR_CNT[2] | DEV_ERR_CNT[1] | DEV_ERR_CNT[0] |
| 0b  | 0b  | 0b             | 0b      | 0b             | 0b             | 0b             | 0b             |

D[7:6] RSV

##### D[5] ERROR\_PIN\_FAIL

- Set to 1 when the MCU ESM Module detects a failure on the ERROR/WDI pin, only if NO\_ERROR = 0 (bit D2 in SAFETY\_CHECK\_CTRL register). The device enters the SAFE state when this ERROR\_PIN\_FAIL bit is set to 1 while the device is in the ACTIVE state and NO\_ERROR = 0. Also set to 1 when a DIAGNOSTIC state time-out occurs.
- Cleared by using SPI to write a 0 to the bit or cleared to 0 during reset event. **Note:** in the DIAGNOSTIC state it is also possible to write this bit to 1, leaving it set at 1 will have the same device level impact as a detected failure on the ERROR/WDI pin.

##### D[4] WD\_FAIL

- This bit is set to 1 on the next bad event when the watchdog fail counter reaches a count of 7 (that is 7 + 1) (the WD\_FAIL\_CNT[2:0] bits in the SAFETY\_STAT\_2 register) when the WD\_RST\_EN bit (bit 3 in SAFETY\_FUNC\_CFG) is set to 1. Also set to 1 when the DIAGNOSTIC state time-out occurs.
- Cleared by using the SPI to write a 0 to the bit when the watchdog fail counter is less than 7 or cleared to 0 during a reset event. **Note:** in the DIAGNOSTIC state, writing this bit to 1 is also possible, leaving it set at 1 when exiting the DIAGNOSTIC state causes a transition to the SAFE state.

##### D[3:0] DEV\_ERR\_CNT[3:0]

- Tracks the current device error count.
- Overwritten by SPI WR access, but ONLY in the DIAGNOSTIC mode.

#### 5.5.4.13 SAFETY\_ERR\_PWM\_H Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_SAFETY\_ERR\_PWM\_H)

Write (WR\_SAFETY\_ERR\_PWM\_H). Write update can only occur in the DIAGNOSTIC state. Write access locked through SW\_LOCK command.

**Figure 5-35. SAFETY\_ERR\_PWM\_H Register**

| D7      | D6      | D5      | D4      | D3      | D2      | D1      | D0      |
|---------|---------|---------|---------|---------|---------|---------|---------|
| PWMH[7] | PWMH[6] | PWMH[5] | PWMH[4] | PWMH[3] | PWMH[2] | PWMH[1] | PWMH[0] |
| 1b      | 0b      | 1b      | 0b      | 1b      | 0b      | 0b      | 0b      |

D[7:0] PWMH[7:0]: The ERROR/WDI pin high-phase duration in PWM mode (15-μs resolution)

- Controls the expected high-phase duration with 15-μs resolution
- Use [Equation 17](#) and [Equation 18](#) to calculate the minimum and maximum values for the HIGH pulse duration,  $t_{PWM\_HIGH}$ . (15-μs time reference has 5% accuracy coming from 4-MHz internal oscillator)



#### 5.5.4.14 SAFETY\_ERR\_PWM\_L Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_SAFETY\_ERR\_PWM\_L)

Write (WR\_SAFETY\_ERR\_PWM\_L). Write update can only occur in the DIAGNOSTIC state. Write access locked through SW\_LOCK command.

**Figure 5-36. SAFETY\_ERR\_PWM\_L Register**

| D7      | D6      | D5      | D4      | D3      | D2      | D1      | D0      |
|---------|---------|---------|---------|---------|---------|---------|---------|
| PWML[7] | PWML[6] | PWML[5] | PWML[4] | PWML[3] | PWML[2] | PWML[1] | PWML[0] |
| 0b      | 0b      | 1b      | 1b      | 1b      | 1b      | 0b      | 1b      |

**D[7:0] PWML[7:0]:** The ERROR/WDI pin low-phase duration

- Controls expected low-phase duration
  - When the ERR\_CFG bit is 0 (in PWM mode): PWM low-phase duration with 15- $\mu$ s resolution  
Use Equation 19 and Equation 20 to calculate the minimum and maximum values for the LOW pulse duration,  $t_{\text{PWM\_LOW}}$ . (15- $\mu$ s time reference has 5% accuracy coming from 4-MHz internal oscillator)
  - When ERR\_CFG bit is 1 (TMS570 mode): error low duration with 5- $\mu$ s resolution  
Use Equation 15 and Equation 16 to calculate the minimum and maximum values for the LOW duration,  $t_{\text{TMS570\_LOW}}$ . (5- $\mu$ s time reference has 5% accuracy coming from 4-MHz internal oscillator)

#### 5.5.4.15 SAFETY\_PWD\_THR\_CFG Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_SAFETY\_PWD\_THR\_CFG)

Write (WR\_SAFETY\_PWD\_THR\_CFG). Write update can only occur in the DIAGNOSTIC state. Write access locked through SW\_LOCK command.

**Figure 5-37. SAFETY\_PWD\_THR\_CFG Register**

| D7  | D6  | D5  | D4  | D3         | D2         | D1         | D0         |
|-----|-----|-----|-----|------------|------------|------------|------------|
| RSV | RSV | RSV | RSV | PWD_THR[3] | PWD_THR[2] | PWD_THR[1] | PWD_THR[0] |
| 0b  | 0b  | 0b  | 0b  | 1b         | 1b         | 1b         | 1b         |

**D[7:4] RSV**

**D[3:0] PWD\_THR[3:0]:** Device error-count threshold to power down the device

- When the DEV\_ERR\_CNT[3:0] counter reaches the programmed threshold, the device powers down.
- The device recovers with a new wake-up or ignition event.

#### 5.5.4.16 SAFETY\_CFG\_CRC Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_SAFETY\_CFG\_CRC)

Write (WR\_SAFETY\_CFG\_CRC). Write update can only occur in the DIAGNOSTIC state. Write access locked through SW\_LOCK command.

**Figure 5-38. SAFETY\_CFG\_CRC Register**

| D7         | D6         | D5         | D4         | D3         | D2         | D1         | D0         |
|------------|------------|------------|------------|------------|------------|------------|------------|
| CFG_CRC[7] | CFG_CRC[6] | CFG_CRC[5] | CFG_CRC[4] | CFG_CRC[3] | CFG_CRC[2] | CFG_CRC[1] | CFG_CRC[0] |
| 0b         | 0b         | 0b         | 1b         | 0b         | 0b         | 0b         | 0b         |

**D[7:0] CFG\_CRC[7:0]:** The CRC8 value for the safety configuration registers

## 5.5.4.17 Diagnostics

### 5.5.4.17.1 DIAG\_CFG\_CTRL Register

**Initialization source:** NPOR, post LBIST reinitialization

**Controller access:** Read (RD\_DIAG\_CFG\_CTRL)

Write (WR\_DIAG\_CFG\_CTRL)

**Figure 5-39. DIAG\_CFG\_CTRL Register**

| D7     | D6      | D5      | D4         | D3         | D2         | D1         | D0         |
|--------|---------|---------|------------|------------|------------|------------|------------|
| MUX_EN | SPI_SDO | MUX_OUT | INT_CON[2] | INT_CON[1] | INT_CON[0] | MUX_CFG[1] | MUX_CFG[0] |
| 0b     | 0b      | 0b      | 0b         | 0b         | 0b         | 0b         | 0b         |

**D[7] MUX\_EN:** Enable diagnostic MUX output

0b = Disabled (tri-stated)

1b = Enabled

**D[6] SPI\_SDO:** To control the SPI\_SDO output-buffer state during an interconnect test

To check the SDO diagnostics use the following sequence:

- MUX\_CFG[1:0] configuration must be 01b (Digital MUX Mode)
- SPI\_NCS must be kept HIGH
- The state of the SDO pin is controlled by the SPI\_SDO bit

**D[5] MUX\_OUT:** Diagnostic MUX output-state control bit

**Note:** When the MUX\_CFG bits are set to 00b and the MUX\_EN bit is set to 1

**D[4:2] INT\_CON[2:0]:** Device interconnect-test configuration bits

000b = No active interconnect test

001b = ERR input state observed on the diagnostic MUX output

010b = SPI\_NCS input state observed on the diagnostic MUX output

011b = SPI\_SDI input state observed on the diagnostic MUX output

100b = SPI\_SCLK input observed on the diagnostic MUX output

101b = Not applicable

110b = Not applicable

111b = Not applicable

**D[1:0] MUX\_CFG[1:0]:** Diagnostic MUX configuration

00b = The MUX output is controlled by MUX\_OUT bit (bit 5 in DIAG\_CFG\_CTRL register)

01b = Digital MUX mode

10b = Analog MUX mode

11b = Device interconnect mode (input-pins interconnect test)

### 5.5.4.17.2 DIAG\_MUX\_SEL Register

**Initialization source:** NPOR, post LBIST reinitialization

**Controller access:** Read (RD\_DIAG\_MUX\_SEL)

Write (WR\_DIAG\_MUX\_SEL)

**Figure 5-40. DIAG\_MUX\_SEL Register**

| D7         | D6         | D5         | D4         | D3         | D2         | D1         | D0         |
|------------|------------|------------|------------|------------|------------|------------|------------|
| MUX_SEL[7] | MUX_SEL[6] | MUX_SEL[5] | MUX_SEL[4] | MUX_SEL[3] | MUX_SEL[2] | MUX_SEL[1] | MUX_SEL[0] |
| 0b         | 0b         | 0b         | 0b         | 0b         | 0b         | 0b         | 0b         |

**D[7:0] MUX\_SEL[7:0]:** Diagnostic MUX channel select

**Note:** The MUX channel table is dependent on the MUX\_CFG[1:0] bit settings in the DIAG\_CFG\_CTRL register (see [Section 5.5.4.17.1](#))

## 5.5.5 Watchdog Timer

### 5.5.5.1 WD\_TOKEN\_FDBK Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_WD\_TOKEN\_FDBK)

Write (WR\_WD\_TOKEN\_FDBK). Write update can only occur in the DIAGNOSTIC state. Write access locked through SW\_LOCK command.

**Figure 5-41. WD\_TOKEN\_FDBK Register**

| D7      | D6      | D5      | D4      | D3            | D2            | D1            | D0            |
|---------|---------|---------|---------|---------------|---------------|---------------|---------------|
| FDBK[3] | FDBK[2] | FDBK[1] | FDBK[0] | TOKEN_SEED[3] | TOKEN_SEED[2] | TOKEN_SEED[1] | TOKEN_SEED[0] |
| 0b      | 0b      | 0b      | 0b      | 0b            | 0b            | 0b            | 0b            |

**D[7:4] FDBK[3:0]:** Watchdog question (token) FSM feedback configuration bits

- FDBK [3:0] bits control the sequence of generated questions and Markov chain polynomial
- The device has a set of 16 generated questions, repetition or sequence ordering can be adjusted by the FDBK[3:0] bits
- FDBK[3:2] controls the question (TOKEN) generation for the watchdog in Q&A mode
- FDBK[2:1] controls the LFSR configuration for the watchdog question (TOKEN) generation
- FDBK[0] RSV

**D[3:0] TOKEN\_SEED[3:0]:** Watchdog token seed value, used to generate a set of new questions (tokens)

- The token seed value can be updated by the MCU only after watchdog is reinitialization in the DIAGNOSTIC state after RESET. The new TOKEN\_SEED[3:0] value takes effect after another transition through the RESET state with AUTO\_BIST\_DIS = 1:
- Only for Q&A Mode

### 5.5.5.2 WD\_WIN1\_CFG Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_WD\_WIN1\_CFG)

Write (WR\_WD\_WIN1\_CFG). Write update can only occur in the DIAGNOSTIC state. Write access locked through SW\_LOCK command.

**Figure 5-42. WD\_WIN1\_CFG Register**

| D7  | D6    | D5    | D4    | D3    | D2    | D1    | D0    |
|-----|-------|-------|-------|-------|-------|-------|-------|
| RSV | RT[6] | RT[5] | RT[4] | RT[3] | RT[2] | RT[1] | RT[0] |
| 0b  | 1b    | 1b    | 1b    | 1b    | 1b    | 1b    | 1b    |

**D[7]** RSV

**D[6:0] RT[6:0]:** Watchdog Window 1 duration setting

- See [Equation 1](#) and [Equation 2](#) to calculate the minimum and maximum values for the  $t_{WIN1}$  time period.

### 5.5.5.3 WD\_WIN2\_CFG Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_WD\_WIN2\_CFG)

Write (WR\_WD\_WIN2\_CFG). Write update can only occur in the DIAGNOSTIC state. Write access locked through SW\_LOCK command.

**Figure 5-43. WD\_WIN2\_CFG Register**

| D7  | D6  | D5  | D4    | D3    | D2    | D1    | D0    |
|-----|-----|-----|-------|-------|-------|-------|-------|
| RSV | RSV | RSV | RW[4] | RW[3] | RW[2] | RW[1] | RW[0] |
| 0b  | 0b  | 0b  | 1b    | 1b    | 0b    | 0b    | 0b    |

**D[7:5]** RSV

**D[4:0] RW[4:0]:** Watchdog Window 2 duration setting

- See [Equation 3](#) and [Equation 4](#) to calculate the minimum and maximum values for the  $t_{WIN2}$  time period.

#### 5.5.5.4 WD\_TOKEN\_VALUE Register

**Initialization source:** NPOR, post LBIST reinitialization

**Controller access:** Read only (RD\_WD\_TOKEN\_VALUE)

**Figure 5-44. WD\_TOKEN\_VALUE Register**

| D7         | D6  | D5  | D4  | D3       | D2       | D1       | D0       |
|------------|-----|-----|-----|----------|----------|----------|----------|
| WD_FAIL_TH | RSV | RSV | RSV | TOKEN[3] | TOKEN[2] | TOKEN[1] | TOKEN[0] |
| 1b         | 0b  | 0b  | 0b  | 0b       | 0b       | 0b       | 0b       |

**D[7] WD\_FAIL\_TH**

- Set to 1 when the watchdog fail counter reaches a count of 5 or higher (WD\_FAIL\_CNT[2:0] bits in the SAFETY\_STAT\_2 register)
- Cleared to 0 when the watchdog fail counter reaches a count of less than 5 (WD\_FAIL\_CNT[2:0] bits in the SAFETY\_STAT\_2 register)

**D[6:4] RSV**

**D[3:0] TOKEN[3:0]:** watchdog question (token)

- The MCU must read (or calculate) the current question (token) to generate a correct answer bytes.
- Only for Q&A mode

#### 5.5.5.5 WD\_STATUS Register

**Initialization source:** NPOR, post LBIST reinitialization

**Controller access:** Read only (RD\_WD\_STATUS)

**Figure 5-45. WD\_STATUS Register**

| D7             | D6             | D5         | D4           | D3         | D2      | D1       | D0           |
|----------------|----------------|------------|--------------|------------|---------|----------|--------------|
| WD_ANSW_CNT[1] | WD_ANSW_CNT[0] | ANSWER_ERR | WD_WRONG_CFG | WD_CFG_CHG | SEQ_ERR | TIME_OUT | ANSWER_EARLY |
| 1b             | 1b             | 0b         | 0b           | 0b         | 0b      | 0b       | 0b           |

**D[7:6] WD\_ANSW\_CNT[1:0]:** Current watchdog answer count

- Only for Q&A mode

**D[5] ANSWER\_ERR:** Watchdog error-status bit to show the incorrect Answer-x byte (formerly TOKEN\_ERR)

- This bit is set to 1 as soon as an Answer-x byte (WD\_TOKEN\_RESPx) is not correct. This flag is cleared if the following answer is correct again or at the beginning of a new watchdog sequence. This bit is not cleared on SPI read-out.
- Only for Q&A mode

**D[4] WD\_WRONG\_CFG**

- Set to 1 when either the WD\_WIN1\_CFG or WD\_WIN2\_CFG bits are set to 00h.

**D[3] WD\_CFG\_CHG:** Watchdog configuration-change status bit

- This bit is set to 1 when WD\_WIN1\_CFG or WD\_WIN2\_CFG setting is changed. This bit is cleared at the beginning of a new watchdog sequence.

**D[2] SEQ\_ERR:** Any of the answer bytes are wrong

- Incorrect timing or wrong answer
- Only for Q&A mode

**D[1] TIME\_OUT:** No watchdog event (trigger or four answer-x bytes) received within the watchdog sequence (time-out event)

- In trigger mode (default): set to 1 when no trigger has been received on the ERROR/WDI pin during the watchdog sequence
- In Q&A mode: set to 1 when less than four Answer-x bytes have been received during the watchdog sequence
- This flag can be used to resynchronize the MCU timing to the device watchdog.
- Cleared to 0 by SPI read access, cleared to 0 after a watchdog *good event* or *bad event*, or cleared to 0 during reset event.

**Note:** In the DIAGNOSTIC state, writing this bit to 1 is possible, leaving it set at 1 has the same device level impact as a detected failure on the ERROR/WDI pin.

**D[0] ANSWER\_EARLY:** Answer-x bytes completed too early or trigger too early (formerly TOKEN\_EARLY)

- Set to 1 if the four answer bytes are returned during Window 1 or the trigger occurs in Window 1

### 5.5.5.6 WD\_ANSWER Register

**Initialization source:** NPOR

**Controller access:** Write only (WR\_WD\_ANSWER)

**Figure 5-46. WD\_ANSWER Register**

| D7         | D6         | D5         | D4         | D3         | D2         | D1         | D0         |
|------------|------------|------------|------------|------------|------------|------------|------------|
| WD_ANSW[7] | WD_ANSW[6] | WD_ANSW[5] | WD_ANSW[4] | WD_ANSW[3] | WD_ANSW[2] | WD_ANSW[1] | WD_ANSW[0] |
| 0b         | 0b         | 0b         | 0b         | 0b         | 0b         | 0b         | 0b         |

**D[7:0]** **WD\_ANSW[7:0]:** answer bytes

- See [Section 5.4.15.4](#) for details on answer bytes
- Only for Q&A mode

## 5.5.6 Sensor Supply

### 5.5.6.1 SENS\_CTRL Register

**Initialization source:** NPOR

**Controller access:** Read (RD\_SENS\_CTRL)

Write (WR\_SENS\_CTRL)

**Figure 5-47. SENS\_CTRL Register**

| D7  | D6  | D5  | D4      | D3  | D2  | D1  | D0        |
|-----|-----|-----|---------|-----|-----|-----|-----------|
| RSV | RSV | RSV | VDD5_EN | RSV | RSV | RSV | VSOUT1_EN |
| 0b  | 0b  | 0b  | 1b      | 0b  | 0b  | 0b  | 0b        |

**D[7:5]** RSV

**D[4]** **VDD5\_EN:** If cleared to 0, the VDD5 regulator turns off.

- This bit is set to 1 by default, and is cleared in case of the VDD5 over temperature condition (indicated by the VDD5\_OT bit D1 in the SAFETY\_STAT1 register).

**Note:** When the VDD5 regulator is disabled, the VDD5\_ILIM bit (bit D7 in the SAFETY\_STAT\_1 register) is set to 1 and remains set to 1 as long as the VDD5 regulator is disabled (or the VDD5\_EN bit is 0). However, the VDD5\_OV and VDD5\_UV bits reflect an overvoltage or undervoltage condition on the VDD5 regulator.

**D[3:1]** RSV

**D[0]** **VSOUT1\_EN:** Sensor-supply enable bit (set this bit to 1 to enable the VSOUT1 sensor supply)

- This bit is cleared to 0 by default, and must be set to 1 by the MCU to enable the VSOUT1 sensor supply. In case of a VSOUT1 overtemperature condition (indicated by the VSOUT1\_OT bit D2 in the SAFETY\_STAT1 regulator), the VSOUT1 regulator is disabled and this bit, VSOUT1\_EN, is cleared to 0. When the overtemperature condition in the VSOUT1 sensor supply is no longer present, the VSOUT1 sensor supply must be reenabled.

## 6 Application and Implementation

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### NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

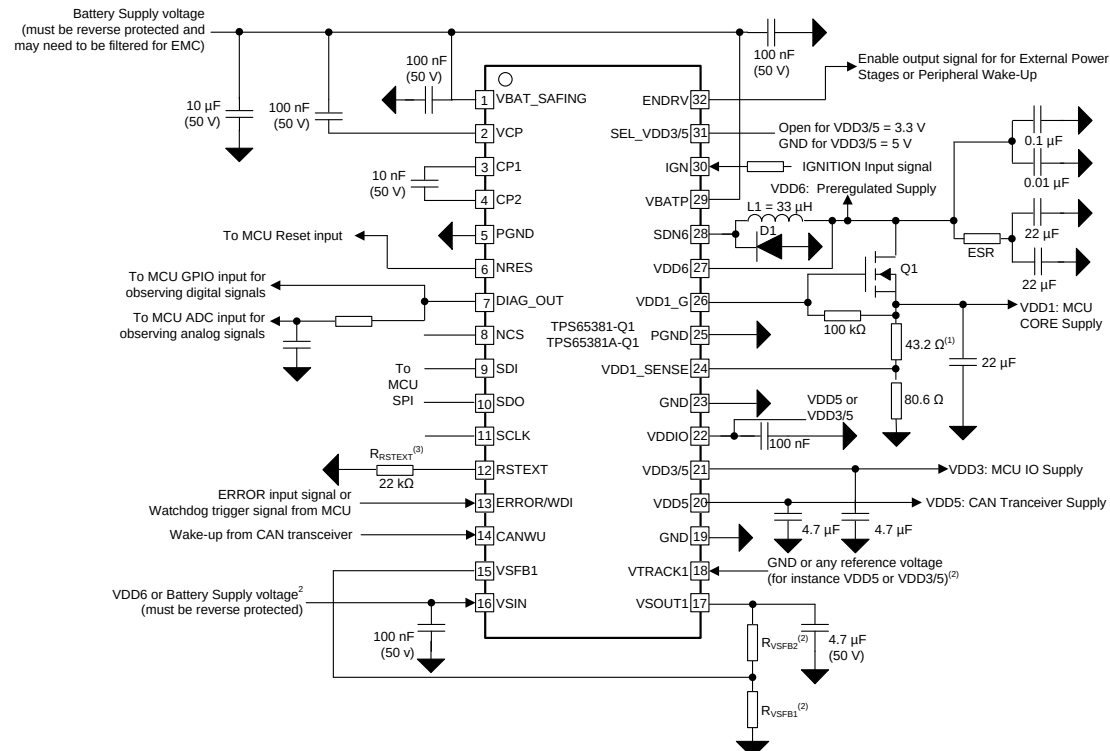
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### 6.1 Application Information

The TPS65381A-Q1 device is a multirail power supply including one buck preregulator, one linear controller, one 5-V linear regulator, one programmable 3.3-V or 5-V linear regulator, and one linear tracking regulator with protection against short to battery and ground. The device has many diagnostic and monitoring functions. This device provides a power-management basis for many different applications.

### 6.2 Typical Application

The following design requirements and design procedure are an example of how to select component values for the TPS65381A-Q1 device for a typical application. Because many of the regulators are adjustable, the equations should be used to calculate the component values for the specific application. For additional reference, also refer to the design checklist and application notes listed in [Section 9.1.1](#).



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Example components:

- Q1: BUK9213-30A
- D1: Vishay SS3H09/10, OnSemi MBRS340T3
- D2: ROHM UDZSTE-176.2B
- L1: TDK CLF10060NIT-330M-D or COILCRAFT MSS1246T-333ML

NOTE:

1. 43.2  $\Omega$  for 1.23-V output voltage (Recommended for TI TMS570 MCU). Change this resistor to obtain different VDD1 output voltage, VDD1\_SENSE = 800 mV. The tolerance of the resistors in this resistor divider will impact VDD1 regulation and voltage monitoring tolerance. Resistors with 0.1% tolerance are recommended.
2. R<sub>VSFB1</sub> and R<sub>VSFB2</sub> configure the VSOUT1 voltage
  - Pin 16 (VSIN) to be connected either to pin 27 (VDD6) for VSOUT1  $\leq$  5 V or to pin 29 (VBATP) for 5 V < VSOUT1 < 9.5 V
  - Pin 18 (VTRACK1) to be connected to GND for non-tracking mode, or a reference voltage (for example VDD5 or VDD3/5) for tracking mode.
  - The tolerance of the resistors in this resistor divider will impact VSOUT1 regulation and voltage monitoring tolerance. Resistors with 0.1% tolerance are recommended.
  - See [Section 5.3.5](#) for details.
3. R<sub>RSEXT</sub> configures the Reset Extension time. See the *Reset and Enable outputs* section of [Section 4.5](#)

### Figure 6-1. Typical Application Diagram

### 6.2.1 Design Requirements

While selecting capacitors for the application consider the following characteristics:

- The effective capacitance at the operating voltage must be used when selecting the proper capacitor. Capacitors derate with operating voltage, sometimes as much as 70%. Therefore the capacitance of the circuit could be outside of the specified value for the capacitor as listed in [Section 4](#).
- The temperature and lifetime of the capacitor can also impact the effective capacitance and should be considered.
- The voltage ratings of the capacitor should be considered, especially on the high-voltage input circuits that can also experience transient voltages.

These impacts must all be considered when selecting a capacitor so that the circuit has the specified capacitance required for this device at the application operating conditions of the capacitor such as temperature, voltage, and lifetime.

The VBATP and VBAT\_SAFING pins are the supply inputs to the device. These supplies must be reverse-battery protected. The supplies should also be adequately protected against transients and have sufficient noise filtering for the intended application. If the application has noisy and high-current output drives that are connected to either the VBATP pin, VBAT\_SAFING pin, or both, additional filtering may be necessary between the output drive and the device.

The IGN pin is a wake-up input to the device. This input provides up to –7 V of protection. Beyond this voltage, the IGN pin must be reverse protected. If the noise can occur longer than the specified deglitch time, the IGN pin should also be adequately protected against transients and have sufficient noise filtering for the intended application.

### 6.2.2 Detailed Design Procedure

#### 6.2.2.1 VDD6 Preregulator

The inductor, output capacitor, and total effective series resistance (ESR) of the output capacitance must be considered to achieve balanced operation of the VDD6 preregulator.

The output inductor must be greater than or equal to the minimum 22-μH inductance. The typical specified inductance is 33 μH, which was selected for this design.

The effective output capacitance for the VDD6 preregulator is specified from 22 μF to 47 μF. An effective capacitance of 22 μF at the 6-V DC operating point was selected for this design. This value allows for additional downstream input capacitance on voltage regulator inputs. To filter high frequencies, use 10-nF and 0.1-μF capacitors in parallel. If higher effective capacitance is used, the voltage ripple is reduced and lowers the required ESR. The effective capacitance of a capacitor should be provided by the capacitor supplier and must be derated for tolerance, lifetime, temperature, and operating voltage.

Because the VDD6 preregulator is a hysteretic architecture, controlled ESR is required with the output capacitance. The specified ESR range is from 100 mΩ to 300 mΩ. Use [Equation 21](#) to calculate the minimum total ESR to achieve balanced operation.

$$R_{ESR} = L / (15 \times C_{Effective}) = 33 / (15 \times 22) = 100 \text{ m}\Omega \quad (21)$$

As an example, the data sheet for the capacitor states that the ESR of the capacitor is 4 mΩ and the parasitic extraction of the PCB design is 6 mΩ. An ESR resistor of 100 mΩ can still be used, or the discrete ESR resistor can be sized to 90 mΩ resulting in a total effective ESR of at least 100 mΩ. If a larger effective capacitance is used, the equation may result in an ESR value below 100 mΩ. In this case, the total ESR should still be brought up to 100-mΩ total ESR minimum to meet the specification.

A high-voltage surface-mount Schottky-rectifier diode, such as SS3H9/10 or MBRS340T3, should be used.

[Figure 6-2](#) shows this configuration.



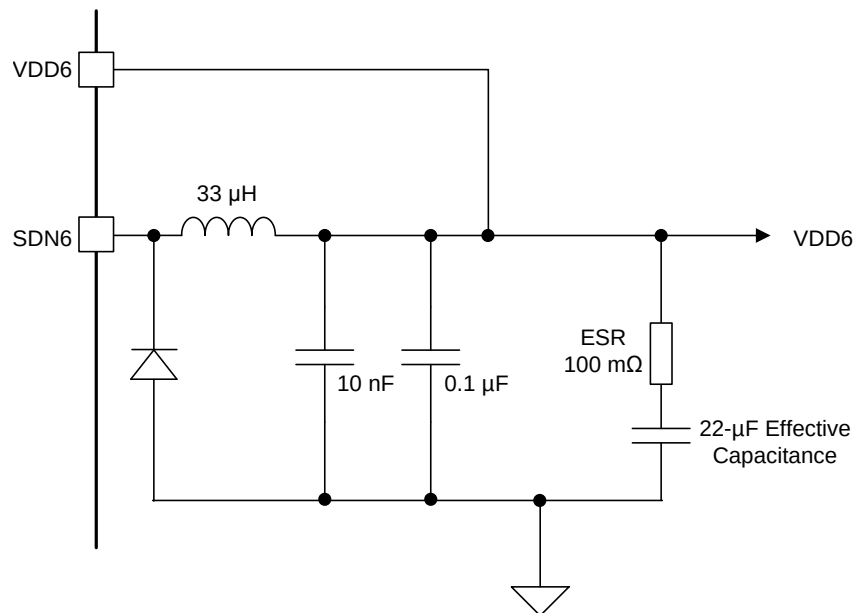


Figure 6-2. VDD6 Design

#### 6.2.2.2 VDD1 Linear Controller

The microprocessor used with the TPS65381A-Q1 device requires a core voltage of 1.23 V.

The output voltage of the VDD1 linear controller is set by a resistor divider from the VDD1 output to ground with the divided voltage connected to the VDD1\_SENSE pin, which must be set to 800 mV. To ensure sufficient bias current through the resistor divider, select a value of R1 as 80.6 Ω. Use Equation 22 to calculate the resistance of R2.

$$R2 = ([VDD1 \times R1] / V_{VDD1\_SENSE}) - R1 = ([1.23 \text{ V} \times 80.6 \Omega] / 0.8 \text{ V}) - 80.6 \Omega = 43.3 \Omega \quad (22)$$

Select the standard value of 43.2 Ω.

#### NOTE

The tolerance of the R1 and R2 resistors in this resistor divider will impact the VDD1 regulation and voltage monitoring tolerance. Resistors with 0.1% tolerance are recommended.

Select an output FET for the VDD1 linear controller that meets the requirements in the *VDD1 – LDO With External FET* specifications in Section 4.5. An example output FET is BUK9213-30A. The gate of the output FET is connected to the VDD1\_G pin. A 100-kΩ resistor is connected between the gate and source of the FET. The drain of the FET is connected to the VDD6 preregulator output, which is used as the supply input for the VDD1 linear controller.

A low-ESR ceramic output capacitor with 22-µF effective capacitance at 1.23 V is used to meet the requirements for the output capacitor that is listed in this data sheet. Depending on the application, this output may require a larger output capacitor to ensure the output does not drop below the required regulation specification during load transients. The VDD1 output capacitance is specified up to 40 µF.

Figure 6-3 shows this configuration.

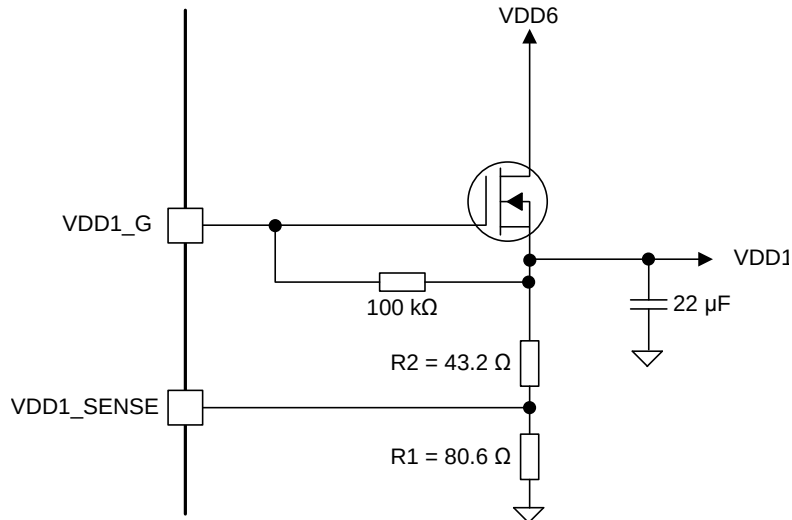


Figure 6-3. VDD1 Design

### 6.2.2.3 VSOUT1 Tracking Linear Regulator, Configured to Track VDD5

The system has a sensor that requires a 5-V supply that must track the VDD5 supply. The configuration should be set up for higher efficiency.

The VDD5 output is connected to the VTRACK1 pin, which configures the regulator for tracking mode. Because the output must track the input, unity gain feedback is used on the VSFB1 pin by connecting it to the VSOUT1 pin.

For efficiency, use the VDD6 preregulator as the supply. Therefore, the VDD6 output is connected to VSIN. A local, low-ESR 100-nF ceramic capacitor is used on the VSIN pin to stabilize the input.

A local, low-ESR 4.7-μF ceramic capacitor is used on the VSOUT1 output for loop stabilization. Depending on the application, this output may require a larger output capacitor to ensure that the output does not drop below the required regulation specification during load transients. The VSOUT1 output capacitance is specified up to 10 μF.

Figure 6-4 shows this configuration.

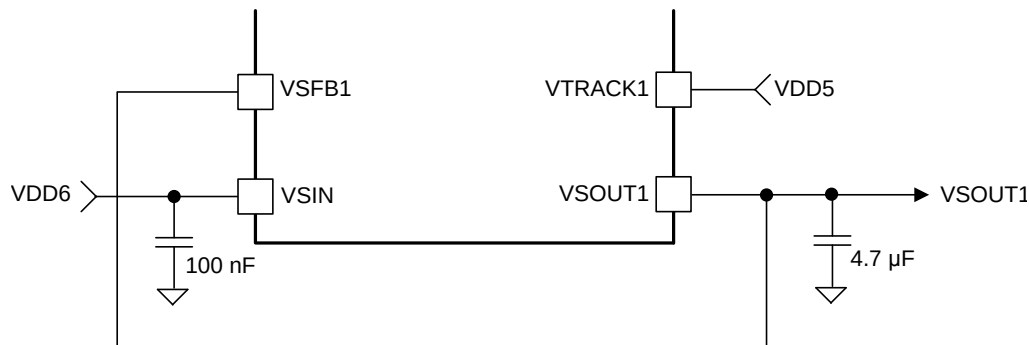


Figure 6-4. VSOUT1 Design—Tracking, No Gain

#### 6.2.2.4 Alternative Use for VSOUT1 Tracking Linear Regulator, Configured for 6-V Output Tracking VDD3/5 In 3.3-V Mode

The system has a sensor that requires a 6-V supply that must track the VDD3/5 supply operating at 3.3 V.

The VDD3/5 supply, operating in 3.3-V mode, is connected to the VTRACK1 pin, which configures the regulator for tracking mode. Because the output must have gain to make the 6-V output track a 3.3-V supply, gain feedback is used on the VSFB1 pin. To achieve the required gain, connect a resistor divider the VSOUT1 and VSFB1 pins. Select a value of 3.3 kΩ for the R<sub>VSFB1</sub> resistor to balance the current through the resistor divider for reasonable bias current and reasonable losses. Use Equation 23 to calculate the resistance of R<sub>VSFB2</sub>.

$$R_{VSFB2} = ([VSOUT1 \times R_{VSFB1}] / VTRACK) - R_{VSFB1} = ([6 \text{ V} \times 3.3 \text{ k}\Omega] / 3.3 \text{ V}) - 3.3 \text{ k}\Omega = 2.7 \text{ k}\Omega \quad (23)$$

Select the standard value of 2.7 kΩ.

#### NOTE

The tolerance of the R<sub>VSFB1</sub> and R<sub>VSFB2</sub> resistors in this resistor divider will impact the VSOUT1 regulation and voltage monitoring tolerance. Resistors with 0.1% tolerance are recommended.

Because the desired VSOUT1 output is greater than 5 V, the VBATP supply must be used for the tracking supply. Therefore, connect the VBATP supply to the VSIN pin. A local, low-ESR 100-nF ceramic capacitor is used on the VSIN pin to stabilize the input.

A local, low-ESR 4.7-μF ceramic capacitor is used on the VSOUT1 pin for loop stabilization. Depending on the application, this output may require a larger output capacitor to ensure that the output does not drop below the required regulation specification during load transients. The VSOUT1 output capacitance is specified up to 10 μF.

Figure 6-5 shows this configuration.

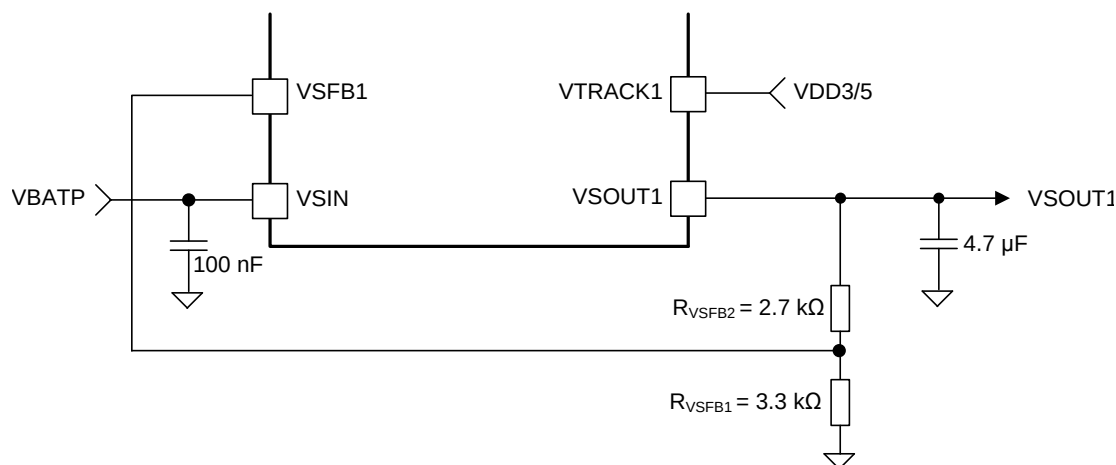


Figure 6-5. VSOUT1 Design—Tracking, With Gain (VDD3/5)

### 6.2.2.5 Alternative Use for VSOUT1 Tracking Linear Regulator, Configured for 9-V Output Tracking to 5-V Input from VDD5

The system has a sensor that requires a 9-V supply that must track the VDD5 supply operating at 5 V.

The VDD5 supply is connected to VTRACK1, which configures the regulator for tracking mode. Because the output must have gain to make the 9-V output track a 5-V supply, gain feedback is used on the VSFB1 pin. To achieve the required gain, connect a resistor divider between the VSOUT1 and VSFB1 pins. Select a value of 3.3 kΩ for the  $R_{VSFB1}$  resistor to balance the current through the resistor divider for reasonable bias current and reasonable losses. Use Equation 24 to calculate the resistance of  $R_{VSFB2}$ .

$$R_{VSFB2} = ([VSOUT1 \times R_{VSFB1}] / VTRACK) - R_{VSFB1} = ([9 \text{ V} \times 3.3 \text{ k}\Omega] / 5 \text{ V}) - 3.3 \text{ k}\Omega = 2.64 \text{ k}\Omega \quad (24)$$

Select the standard value of 2.7 kΩ.

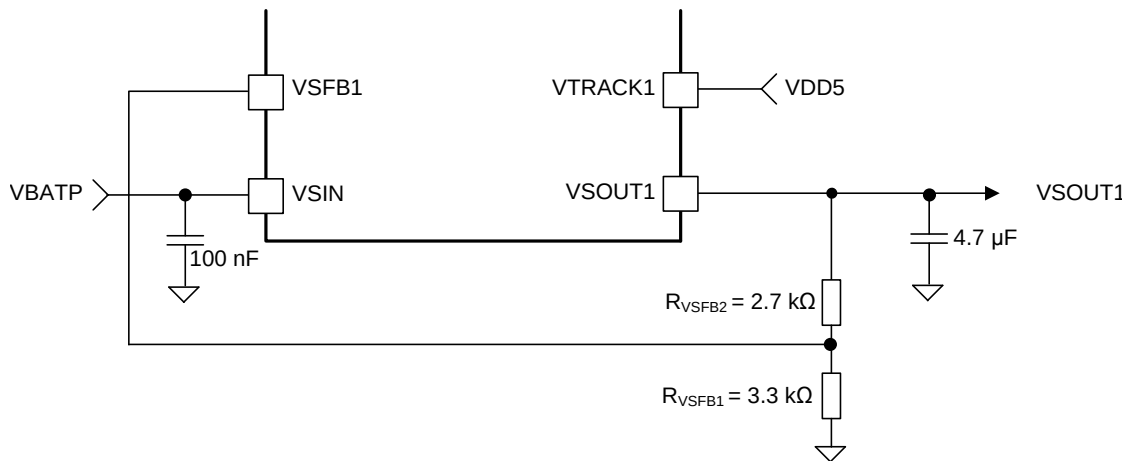
#### NOTE

The tolerance of the  $R_{VSFB1}$  and  $R_{VSFB2}$  resistors in this resistor divider will impact the VSOUT1 regulation and voltage monitoring tolerance. Resistors with 0.1% tolerance are recommended.

Because the desired VSOUT1 output is greater than 5-V, the VBATP supply must be used as the tracking supply. Therefore, connect the VBATP supply to the VSIN pin. A local, low-ESR 100-nF ceramic capacitor is used on the VSIN pin to stabilize the input.

A local, low-ESR 4.7-μF ceramic capacitor is used on the VSOUT1 pin for loop stabilization. Depending on the application, this output may require a larger output capacitor to ensure that the output does not drop below the required regulation specification during load transients. The VSOUT1 output capacitance is specified up to 10 μF.

Figure 6-6 shows this configuration.



**Figure 6-6. VSOUT1 Design—Tracking, With Gain (VDD5)**

### 6.2.2.6 Alternative Use for VSOUT1 Tracking Linear Regulator, Configured in Non-tracking Mode Providing a 4.5-V Output

If the system requires a 4.5-V supply that does not track any other supply, the VTRACK1 pin is connected to ground (GND), which configures the regulator for non-tracking mode. The output is now proportional to a fixed reference voltage ( $V_{ref}$ ) of 2.5 V on the VSFB1 pin. Because the output must have gain to result in a 4.5-V output, gain feedback will be used on the VSFB1 pin. To achieve the required gain, connect a resistor divider between the VSOUT1 and VSFB1 pins. Select a value of 3.3 k $\Omega$  for the RVSFBI resistor to balance the current through the resistor divider for reasonable bias current and reasonable losses. Use Equation 25 to calculate the resistance of RVSFBI.

$$R_{VSFB2} = [(VSOUT1 \times R_{VSFB1}) / V_{ref}] - R_{VSFB1} = [(4.5 \text{ V} \times 3.3 \text{ k}\Omega) / 2.5 \text{ V}] - 3.3 \text{ k}\Omega = 2.64 \text{ k}\Omega \quad (25)$$

Select the standard value of 2.7 k $\Omega$ .

#### NOTE

The tolerance of the RVSFBI and RVSFBI resistors in this resistor divider will impact the VSOUT1 regulation and voltage monitoring tolerance. Resistors with 0.1% tolerance are recommended.

For efficiency, the VDD6 preregulator is the supply and therefore the VDD6 output is connected to the VSIN pin. A local, low-ESR 100-nF ceramic capacitor is used on the VSIN pin to stabilize the input.

A local, low-ESR 4.7- $\mu$ F ceramic capacitor is used on the VSOUT1 pin for loop stabilization. Depending on the application, this output may require a larger output capacitor to ensure that the output does not drop below the required regulation specification during load transients. The VSOUT1 output capacitance is specified up to 10  $\mu$ F.

Figure 6-7 shows this configuration.

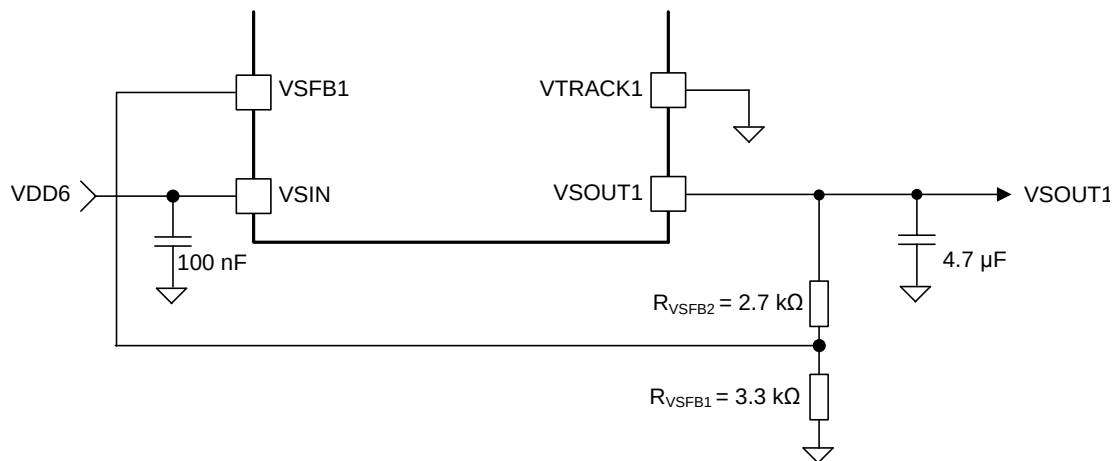


Figure 6-7. VSOUT1 Design—Non-Tracking

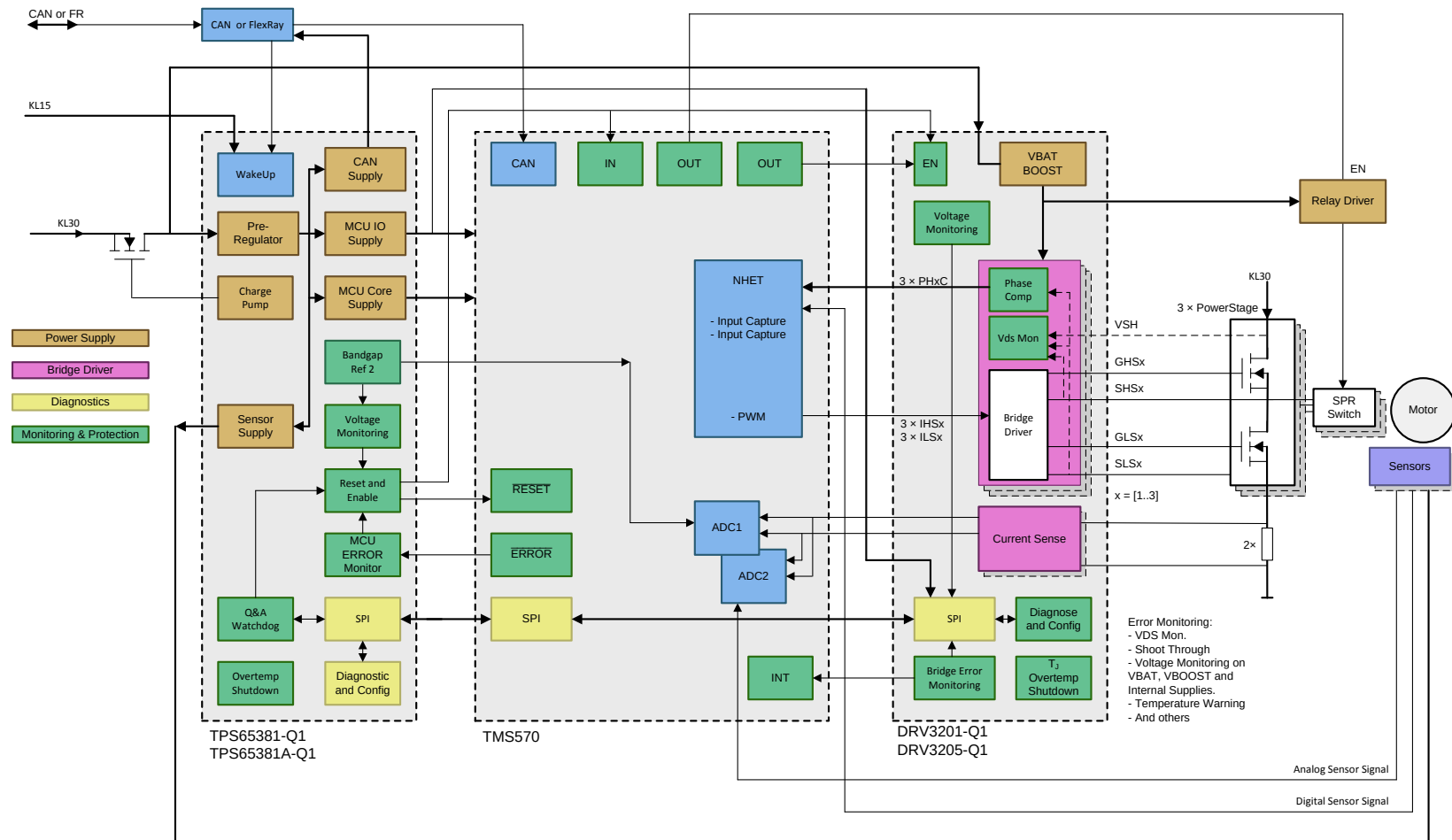
### 6.2.3 Application Curves

For the application curves, see the figures listed in Table 6-1.

Table 6-1. Table of Graphs

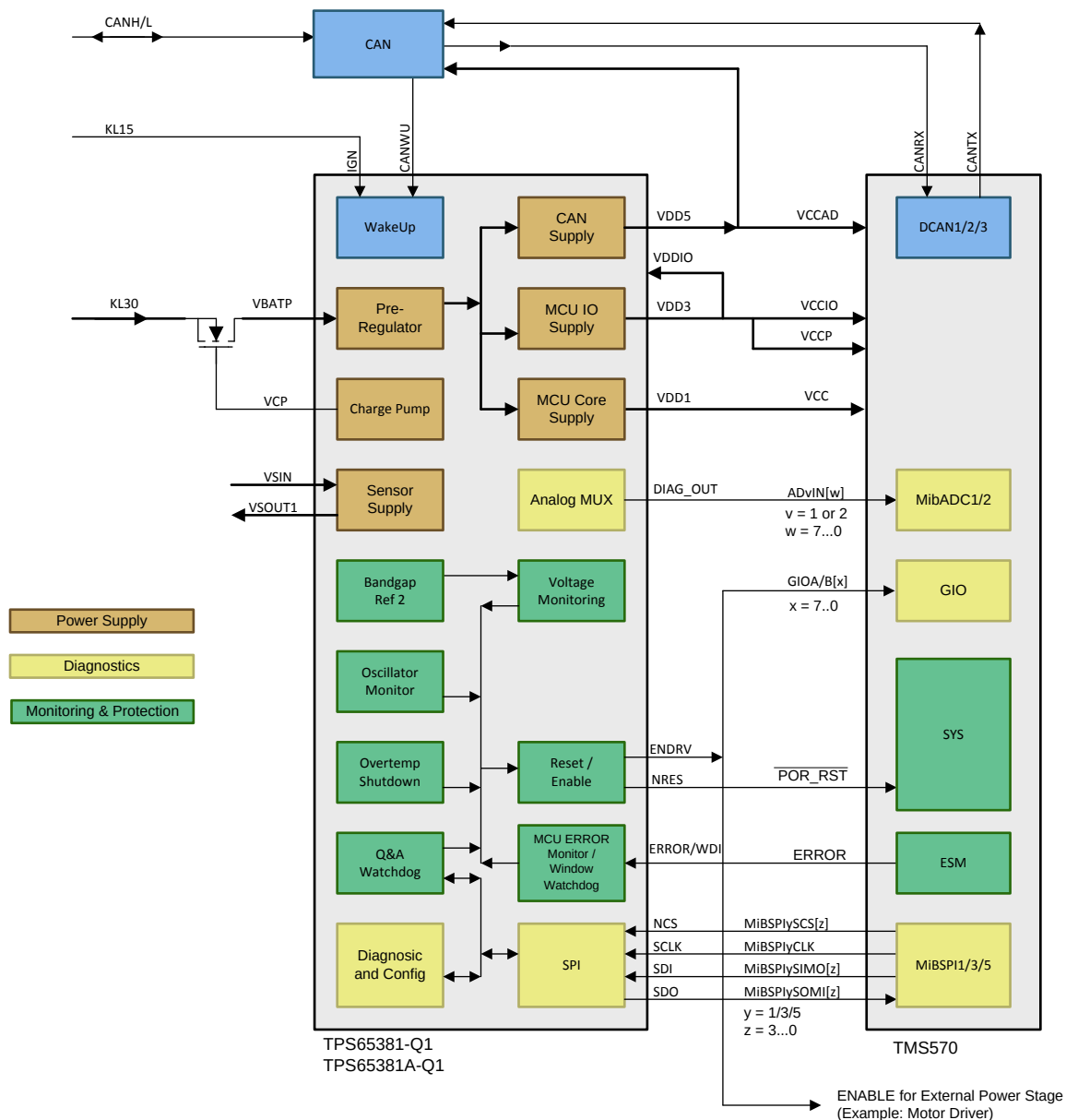
| FIGURE TITLE                           | FIGURE NUMBER |
|----------------------------------------|---------------|
| SPI SDO Buffer Source and Sink Current | Figure 4-3    |
| VDD6 BUCK Efficiency                   | Figure 4-4    |

### 6.3 System Examples



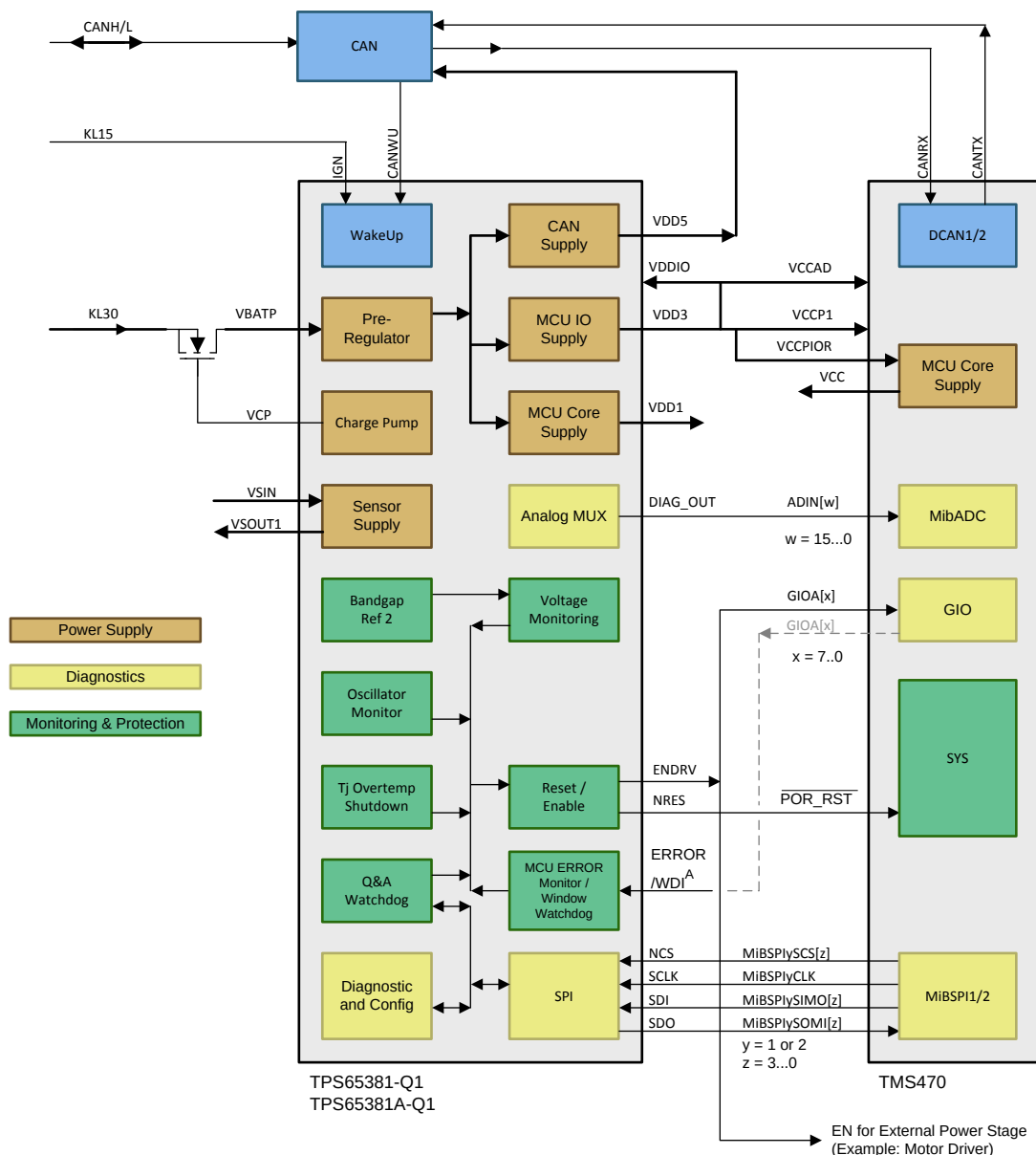
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**Figure 6-8. Electrical Power-Steering Example**



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Figure 6-9. Example TPS65381A-Q1 With TI's TMS570LS



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- A. The ERROR/WDI pin can be configured as an input for the MCU ERROR signal monitor (ESM) (TMS570 dual core or other safety architecture MCU) or as a window watchdog input (TMS470 or other single core MCU).

**Figure 6-10. Example TPS65381A-Q1 With TI's TMS470 (Using an Internal MCU Core Supply)**



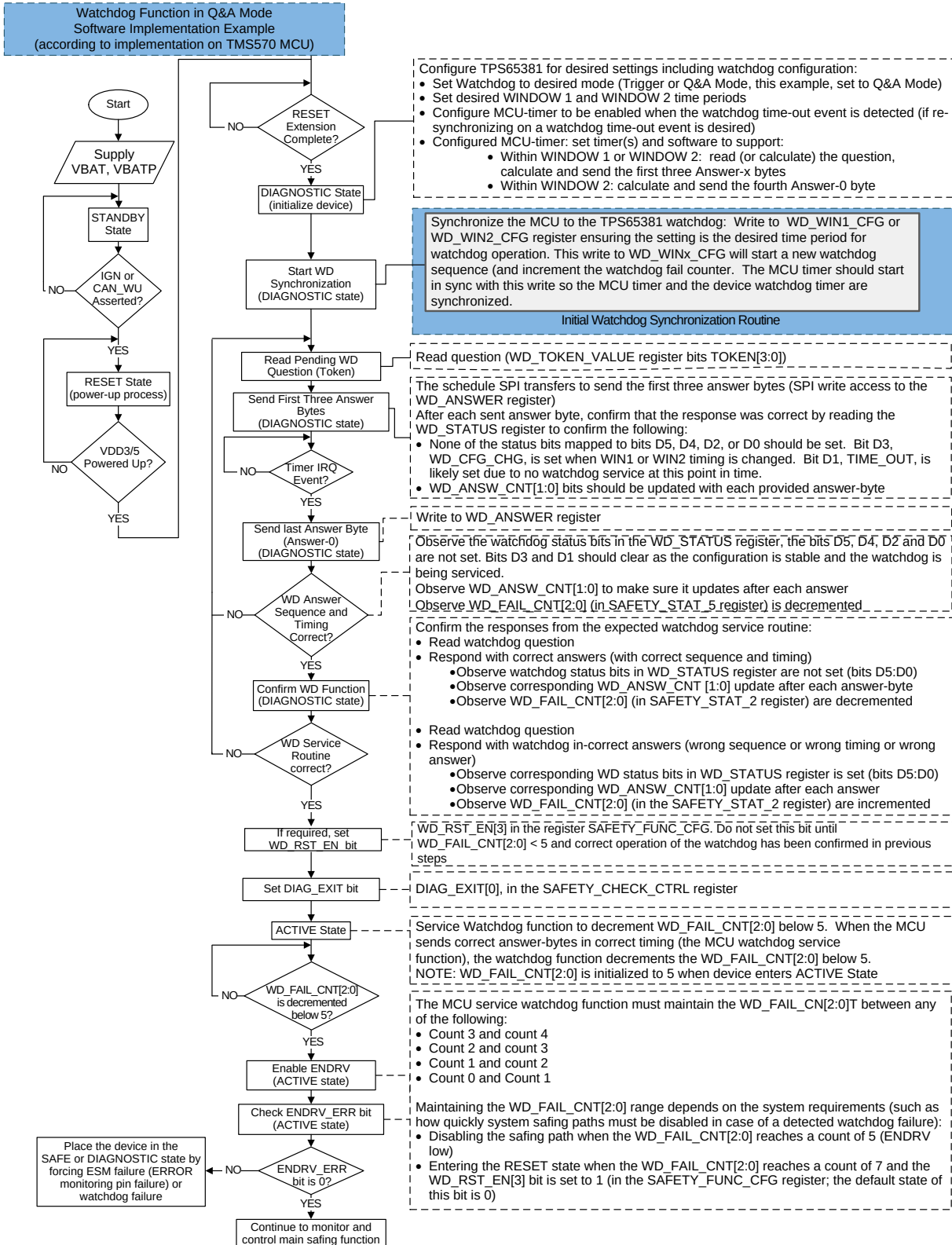
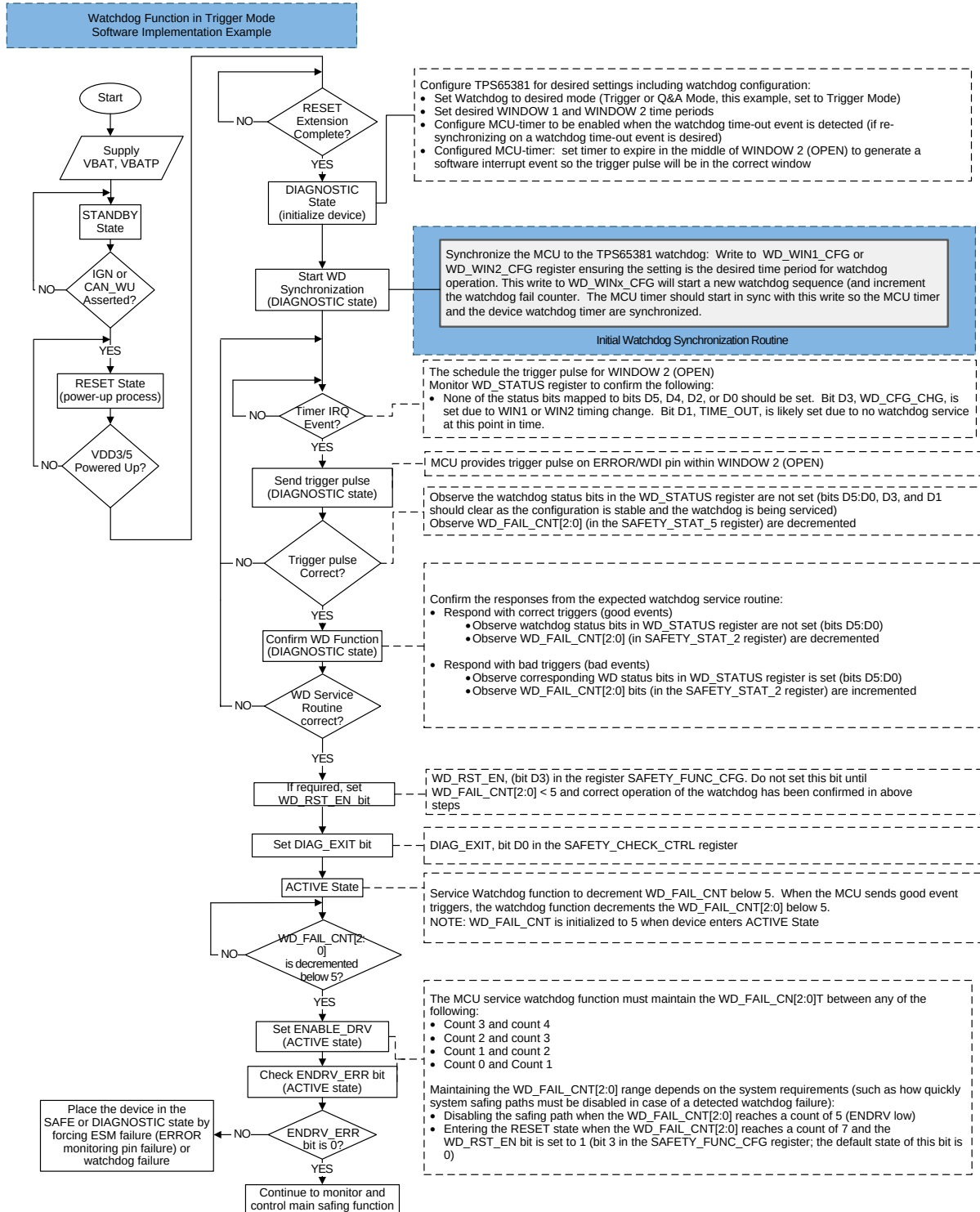


Figure 6-11. Software Flowchart for Configuring and Synchronizing the MCU With the Watchdog in Q&A Mode



**Figure 6-12. Software Flowchart for Configuring and Synchronizing the MCU With the Watchdog in Trigger Mode**

## 7 Power Supply Recommendations

The TPS65381A-Q1 device is designed to operate using an input supply voltage range from 5.8 V to 36 V (CAN, I/O, MCU core, and functional sensor-supply regulators) or 4.5 V to 5.8 V (3.3-V I/O and functional MCU-core voltage). The device has two supply pins: VBATP and VBAT\_SAFING. The VBATP pin is the main supply pin for the device. The VBAT\_SAFING supply pin is for monitoring (VMON) and BG2 functions. Both the VBATP and VBAT\_SAFING supplies must be reverse protected. The VBAT\_SAFING pin should be connected to the VBATP pin with a low impedance connection to minimize voltage differences between the device supply pins. For additional power supply recommendations, refer to the [TPS65381EVM User's Guide](#).

## 8 Layout

### 8.1 Layout Guidelines

#### 8.1.1 VDD6 Buck Preregulator

- Minimize the loop area for the switching loop of the inductor, ESR resistor, output capacitor, and diode.
- Minimize the parasitic trace impedance by using traces that are as wide as possible.
- Minimize the parasitic via impedance by using multiple vias, especially on high current and switching nodes.
- Connect the inductor and diode to SDN6 as close as possible to the pin.
- Connect the diode to PGND (ground plane).
- Connect the ESR resistor and output capacitor in series between VDD6 output (inductor output) and PGND.
- Connect the EMC filter capacitor between VDD6 output and PGND.
- Connect the VDD6 output to the VDD6 pin with routing to avoid coupling switching noise. Trace length should be minimized and as wide a trace as possible. This trace is the supply input to the downstream regulators using VDD6 as a preregulator, parasitic impedance should be minimized.

Additional consideration: add a footprint for a RC snubber circuit if one is required for the application. The RC connects in-series between the SDN6 and PGND pins.

#### 8.1.2 VDD1 Linear Regulator Controller

- Connect the drain of the external FET to VDD6 node, the trace should be minimized so that additional downstream buffering capacitors are not needed.
- Connect the output capacitor to the source of the external FET, the length of this trace should be minimized. Connect the output capacitor to the ground plane.
- Connect the gate drive, VDD1\_G, to the gate of the FET. Connect the resistor between the gate of the FET and the source of the FET, minimize the trace length.
- The resistor divider for sensing and setting the output voltage connects between the source of the FET (VDD1 output) and GND (device signal ground). Do not locate these components and their traces near the switching nodes or high-current traces.

#### 8.1.3 VDD5 and VDD3/5 Linear Regulators

Connect the output capacitor as close as possible between the VDDx output and GND.

#### 8.1.4 VSOUT1 Tracking Linear Regulator

- Connect the output capacitor as close as possible between the VSOUT1 output and GND.
- The resistor divider for sensing and setting the output voltage connects between the VSOUT1 and GND (device signal ground). Do not locate these components and their traces near the switching nodes or high-current traces.
- Connect the local decoupling capacitor between the VSIN and PGND pins. Minimize trace length.
- Route the tracking supply signal, connected to VTRACK1, away from switching nodes or high-current traces.

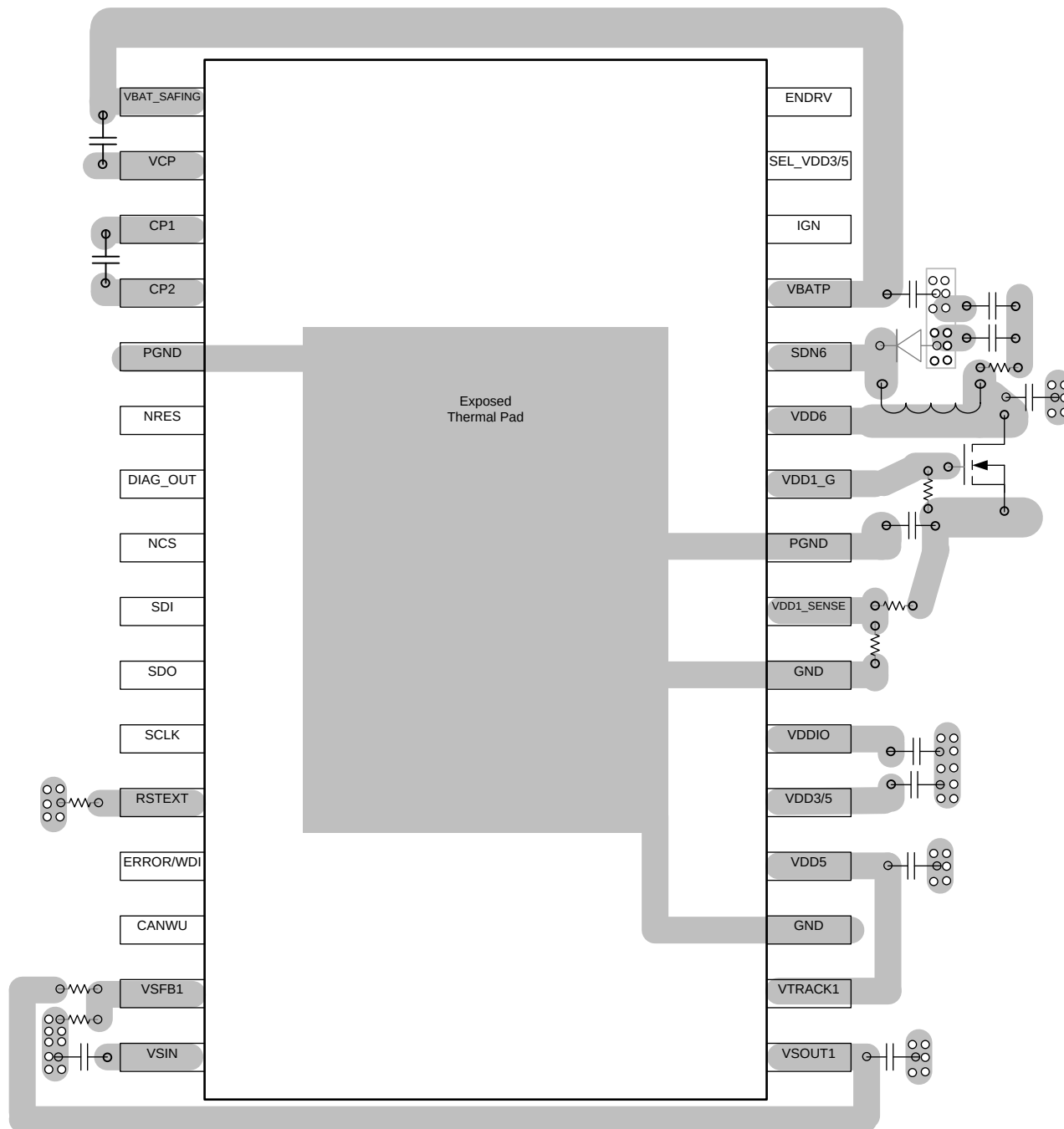
#### 8.1.5 Charge Pump

- Connect the capacitor as close as possible between the CP1 and CP2 pins.
- Connect the capacitor between the VCP pin and VBATP (reverse protected and filtered) supply.

#### 8.1.6 Other Considerations

- Use ground planes. TI recommends having a solid ground plane and connect GND and PGND with as low impedance paths as possible to the ground plane.
- Minimize parasitic impedance on the critical switching and high current paths.
- Short PGNDx and GND to the thermal pad.
- Use a star ground configuration if connecting to a non-ground plane system. Use tie-ins for the voltage-sense feedback ground and local biasing bypass capacitor ground networks to this star ground.
- Connect the local decoupling capacitor between VBATP and PGND. Minimize trace length.

## 8.2 Layout Example



**Figure 8-1. TPS65381A-Q1 Board Layout**

### 8.3 Power Dissipation and Thermal Considerations

The power dissipation of the device in the application has significant impact on the necessary layout and thermal management strategy of the application.

Use the following equations to calculate the estimated power dissipation in the device:

$$P_{VDD6} = (1 - \text{eff}_{VDD6}) \times 6 \text{ V} \times I_{VDD6}$$

where

- $P_{VDD6}$  is a conservative estimation of the power dissipation of VDD6 in the device because some of the efficiency loss is externally in the diode and inductor. A more accurate power estimator is available in the [TPS65381-Q1 and TPS65381A-Q1 Power Estimator](#).
- $\text{eff}_{VDD6}$  is the efficiency of VDD6 buck preregulator according to [Figure 8-2](#).
- $I_{VDD6}$  is the total load current from VDD5, VDD3/5, VDD1, VSOUT1 and any external load connected to VDD6. (26)

$$P_{VDD5} = (6 \text{ V} - 5 \text{ V}) \times I_{VDD5} = 1 \text{ V} \times I_{VDD5}$$

where

- $I_{VDD5}$  is the load current on VDD5. (27)

$$P_{VDD3/5} = (6 \text{ V} - V_{VDD3/5}) \times I_{VDD3/5}$$

where

- $V_{VDD3/5}$  is either 3.3 V or 5 V.
- $I_{VDD3/5}$  is the load current on VDD3/5. (28)

$$P_{VSOUT1} = (V_{VSIN} - V_{VSOUT1}) \times I_{VSOUT1}$$

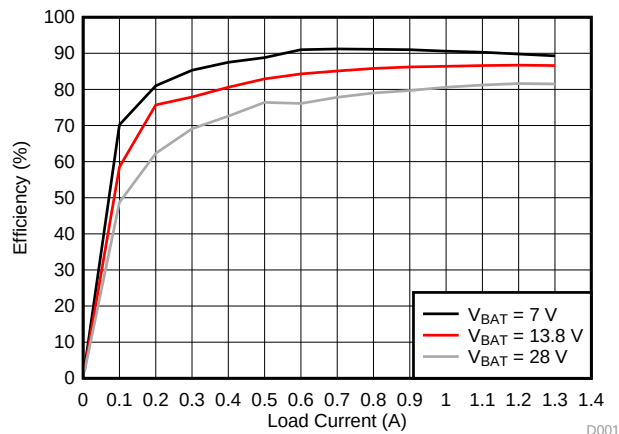
where

- $V_{VSIN}$  is either 6 V (VDD6) or VBATP.
- $V_{VSOUT1}$  is the programmed output voltage of VSOUT1.
- $I_{VSOUT1}$  is the load current on VSOUT1. (29)

$$P_{TOT} = P_{VDD6} + P_{VDD5} + P_{VDD3/5} + P_{VSOUT1}$$

where

- $P_{TOT}$  is the total power dissipation in the device. (30)



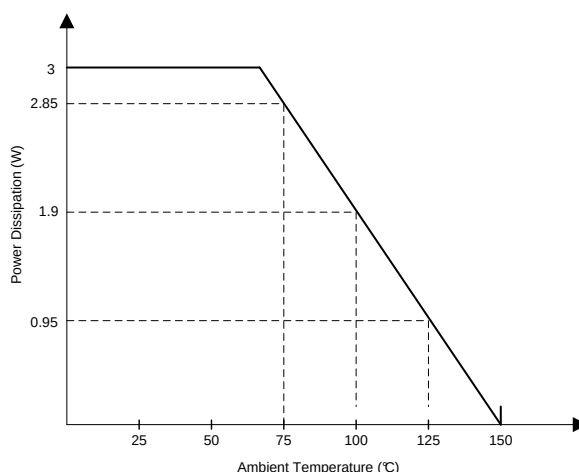
**Figure 8-2. Typical VDD6 BUCK Efficiency**

The useful range of device operation is affected by the supply voltage, application load-current requirements, and the thermal characteristics of the package and printed circuit board (PCB). For the device to be useful over a wide temperature range, the package, PCB and thermal management strategy must allow for the effective removal of the produce heat to keep junction temperature of the device within rated limits.

Use Equation 26 to Equation 30 to calculate the estimated power dissipation. As shown by the equation for VDD6 power dissipation (PVDD6), Equation 27, a large portion of the power dissipation is determined by the efficiency of the VDD6 supply. The efficiency of the VDD6 supply depends on load current and supply voltage as shown in Equation 27.

The 32-pin HTSSOP PowerPAD (DAP) offers an effective means of removing heat from the device junction. As described in *PowerPAD™ Thermally Enhanced Package*, the PowerPAD package offers a lead-frame die pad that is exposed at the base of the package. This thermal pad must be soldered to the copper on the PCB directly underneath the package to create an effective path for removal of heat from the device, and, therefore, to reduce the  $R_{\theta JC}$ . The PCB must be designed with thermal lands and thermal vias to complete the heat removal subsystem, as summarized in *PowerPAD™ Made Easy* and *A Guide to Board Layout for Best Thermal Resistance for Exposed Packages*.

Figure 8-3 shows the thermal derating profile of the 32-pin HTSSOP (DCA) Package With PowerPAD according to  $R_{\theta JA}$  as specified in Section 4.4.



- In applications where high power dissipation and/or poor package thermal resistance is present, the maximum ambient temperature may have to be derated. Maximum ambient temperature ( $T_{Amax}$ ) is dependent on the maximum-operating junction temperature ( $T_{Jmax}$ ), the maximum power dissipation of the device in the application ( $P_{Dmax}$ ), and the junction-to-ambient thermal resistance of the part/package in the application ( $R_{\theta JA}$ ), as given by the following equation:  $T_{Amax} = T_{Jmax} - (R_{\theta JA} \times P_{Dmax})$ .
- Maximum power dissipation is a function of  $T_{Jmax}$ ,  $R_{\theta JA}$ , and  $T_A$ . The maximum-allowable power dissipation at any allowable ambient temperature is  $P_D = (T_{Jmax} - T_A) / R_{\theta JA}$ .

**Figure 8-3. Derating Profile for Power Dissipation Based on High-K JEDEC PCB**

Considering the power dissipation of the device in the specific application is important, which is highly dependent on the supply voltage and load currents, the ambient and board temperatures, and any additional heat sink or cooling strategies necessary to maintain the junction temperature of the device below the maximum junction temperature of 150°C.

#### NOTE

The VDD1 regulator may have significant power dissipation in the external FET depending on the VDD1 voltage and load current. The external FET power dissipation for the VDD1 regulator must be considered in system-level thermal analysis. If better efficiency or thermal performance is needed, a DC-DC regulator could be used instead of the linear regulator controller with external FET. The output voltage of the DC-DC regulator can still be monitored by the VDD1\_SENSE pin similar to the VDD1 output voltage when the VDD1 linear regulator controller is used with an external FET.

**NOTE**

The PowerPAD thermal pad is not directly connected to any leads of the package. However, it is electrically and thermally connected to the substrate, which is the ground (GND) and power ground (PGND) of the device.

**NOTE**

Additional information about thermal analysis and design can be found on [www.ti.com](http://www.ti.com) in the [WEBENCH® Design Center](#) thermal analysis section.

## 9 Device and Documentation Support

### 9.1 Documentation Support

#### 9.1.1 Related Documentation

For related documentation, see the following:

- [Device Behavior Under Slow VBAT Ramp-Up and Ramp-Down](#)
- [DPI Evaluation TPS65381-Q1](#)
- [Efficiency Evaluation TPS65381-Q1](#)
- [Safety Manual for TPS65381-Q1 and TPS65381A-Q1 Multirail Power Supply](#)
- [TPS65381EVM User's Guide](#)
- [TPS65381-Q1 and TPS65381A-Q1 Design Checklist](#)
- [TPS65381-Q1 and TPS65381A-Q1 Power Estimator](#)

### 9.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

### 9.3 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

**TI E2E™ Online Community** The TI engineer-to-engineer (E2E) community was created to foster collaboration among engineers. At [e2e.ti.com](http://e2e.ti.com), you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support** *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

### 9.4 Trademarks

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All other trademarks are the property of their respective owners.

### 9.5 Electrostatic Discharge Caution



This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

### 9.6 Glossary

**TI Glossary** This glossary lists and explains terms, acronyms, and definitions.



## 10 Mechanical, Packaging, and Orderable Information

The following pages include mechanical packaging and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

## PACKAGING INFORMATION

| Orderable part number            | Status<br>(1) | Material type<br>(2) | Package   Pins    | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|----------------------------------|---------------|----------------------|-------------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| <a href="#">TPS65381AQDAPRQ1</a> | Active        | Production           | HTSSOP (DAP)   32 | 2000   LARGE T&R      | Yes         | NIPDAU                               | Level-3-260C-168 HR               | -40 to 125   | TPS65381A           |
| TPS65381AQDAPRQ1.A               | Active        | Production           | HTSSOP (DAP)   32 | 2000   LARGE T&R      | Yes         | NIPDAU                               | Level-3-260C-168 HR               | -40 to 125   | TPS65381A           |
| <a href="#">TPS65381AQDAPTQ1</a> | Active        | Production           | HTSSOP (DAP)   32 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-3-260C-168 HR               | -40 to 125   | TPS65381A           |
| TPS65381AQDAPTQ1.A               | Active        | Production           | HTSSOP (DAP)   32 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-3-260C-168 HR               | -40 to 125   | TPS65381A           |

<sup>(1)</sup> **Status:** For more details on status, see our [product life cycle](#).

<sup>(2)</sup> **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

<sup>(3)</sup> **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

<sup>(4)</sup> **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

<sup>(5)</sup> **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

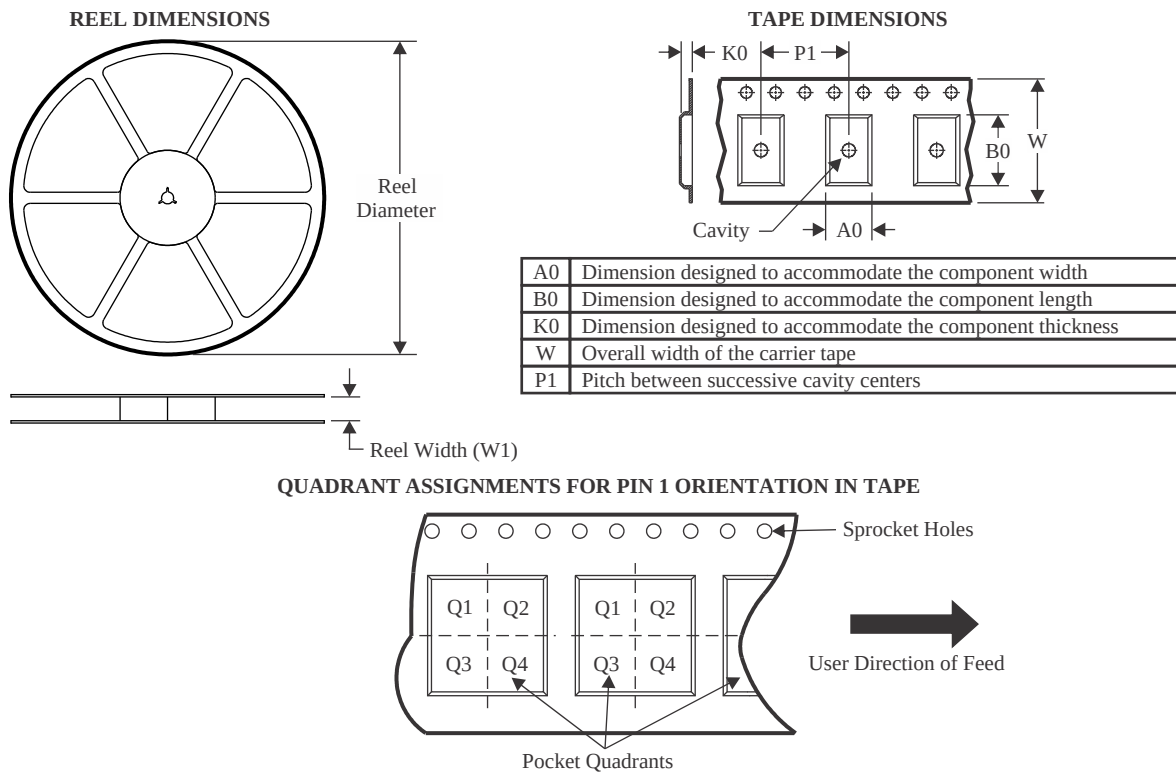
<sup>(6)</sup> **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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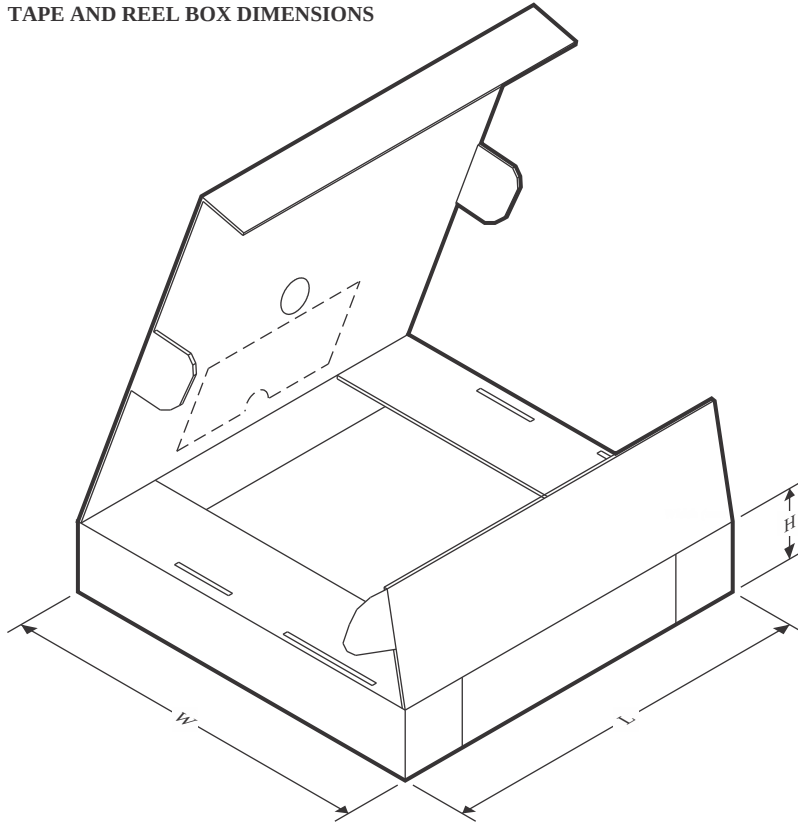
## TAPE AND REEL INFORMATION



\*All dimensions are nominal

| Device           | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|------------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| TPS65381AQDAPRQ1 | HTSSOP       | DAP             | 32   | 2000 | 330.0              | 24.4               | 8.6     | 11.5    | 1.6     | 12.0    | 24.0   | Q1            |
| TPS65381AQDAPTQ1 | HTSSOP       | DAP             | 32   | 250  | 180.0              | 24.4               | 8.6     | 11.5    | 1.6     | 12.0    | 24.0   | Q1            |

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

| Device           | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|------------------|--------------|-----------------|------|------|-------------|------------|-------------|
| TPS65381AQDAPRQ1 | HTSSOP       | DAP             | 32   | 2000 | 350.0       | 350.0      | 43.0        |
| TPS65381AQDAPTQ1 | HTSSOP       | DAP             | 32   | 250  | 213.0       | 191.0      | 55.0        |

## GENERIC PACKAGE VIEW

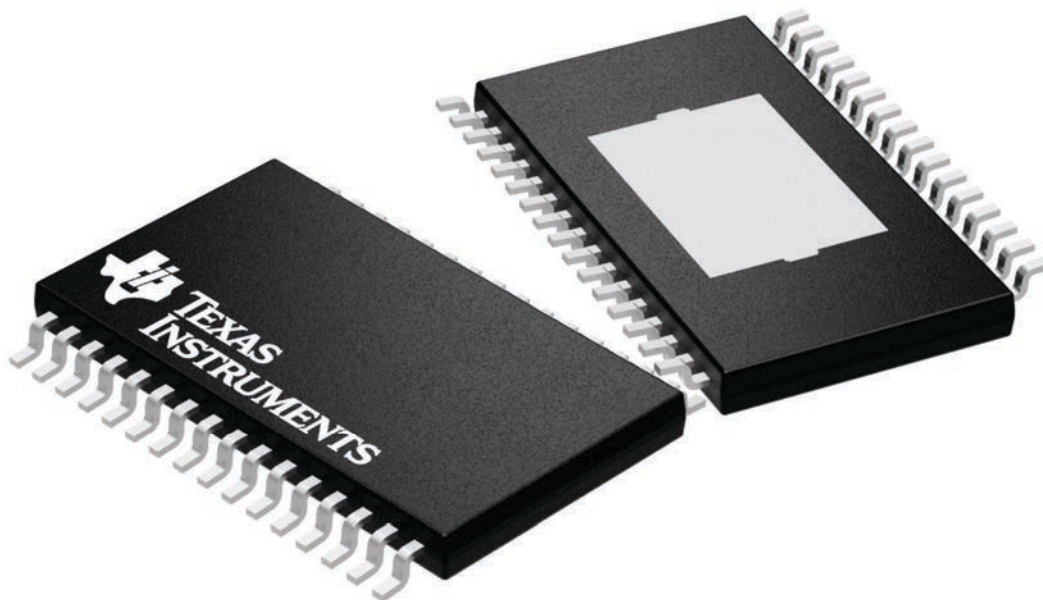
**DAP 32**

**PowerPAD™ TSSOP - 1.2 mm max height**

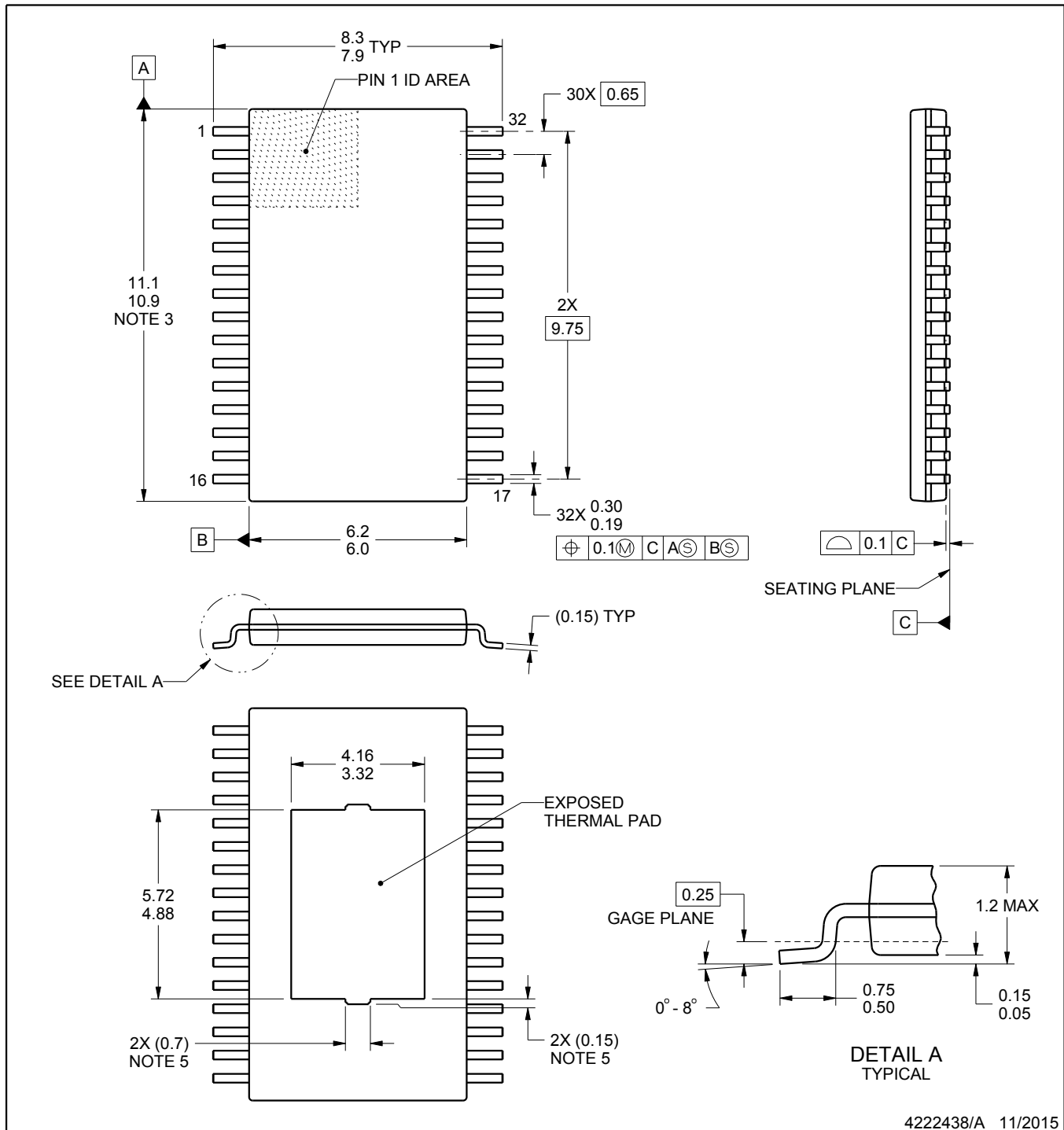
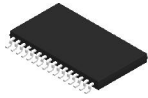
8.1 x 11, 0.65 mm pitch

PLASTIC SMALL OUTLINE

This image is a representation of the package family, actual package may vary.  
Refer to the product data sheet for package details.



4225303/A



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## NOTES:

PowerPAD is a trademark of Texas Instruments.

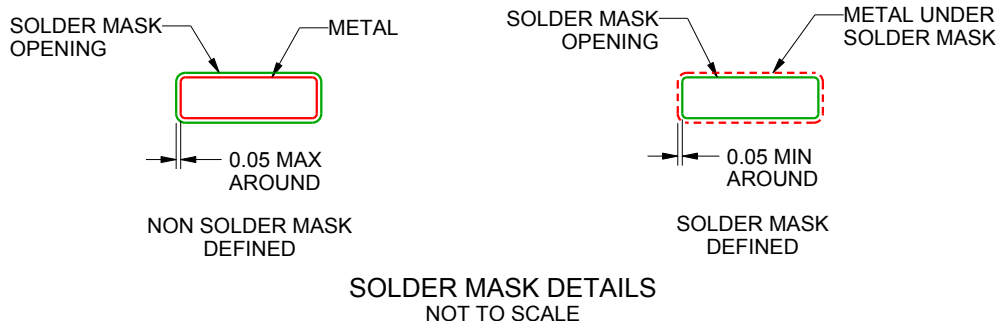
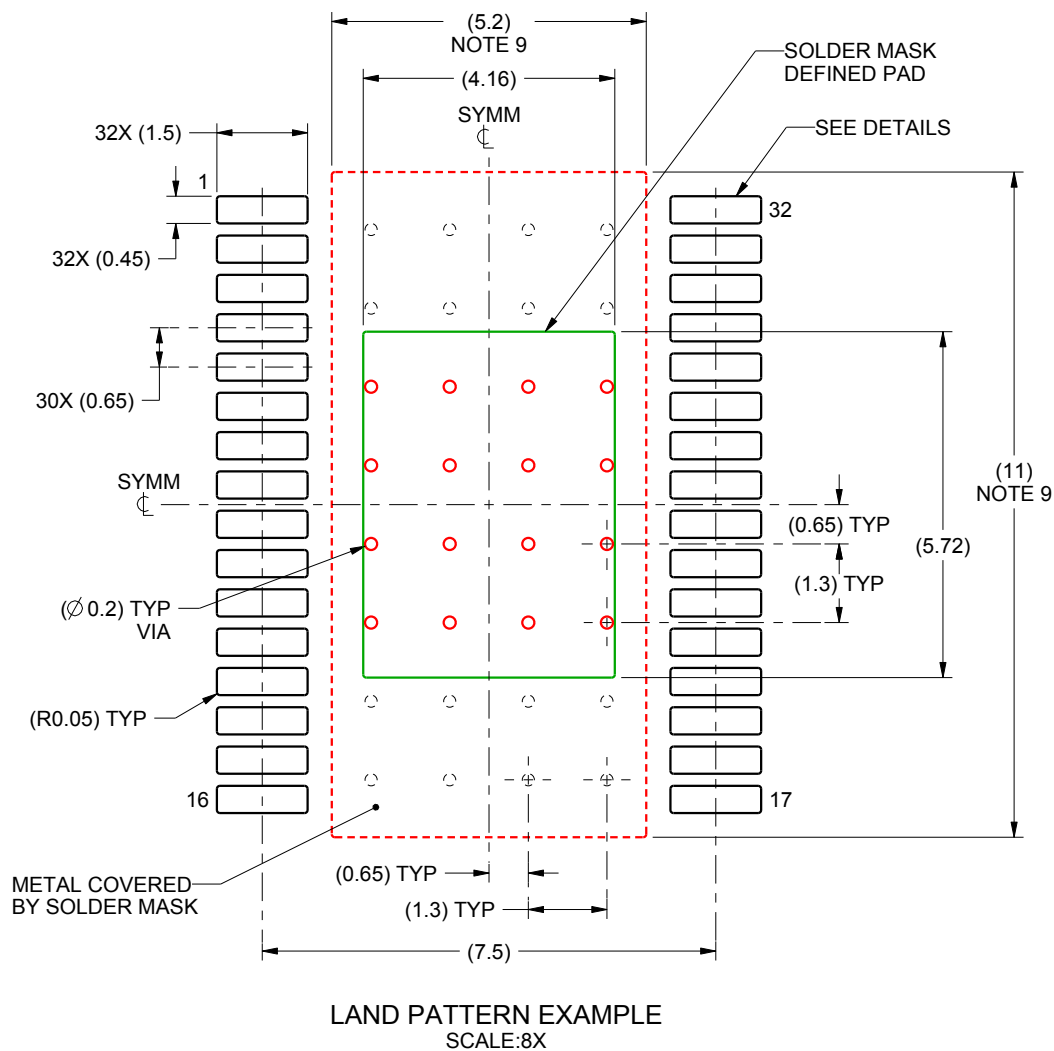
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. Reference JEDEC registration MO-153, variation DCT.
5. Features may not present.

# EXAMPLE BOARD LAYOUT

DAP0032B

PowerPAD™ TSSOP - 1.2 mm max height

PLASTIC SMALL OUTLINE



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NOTES: (continued)

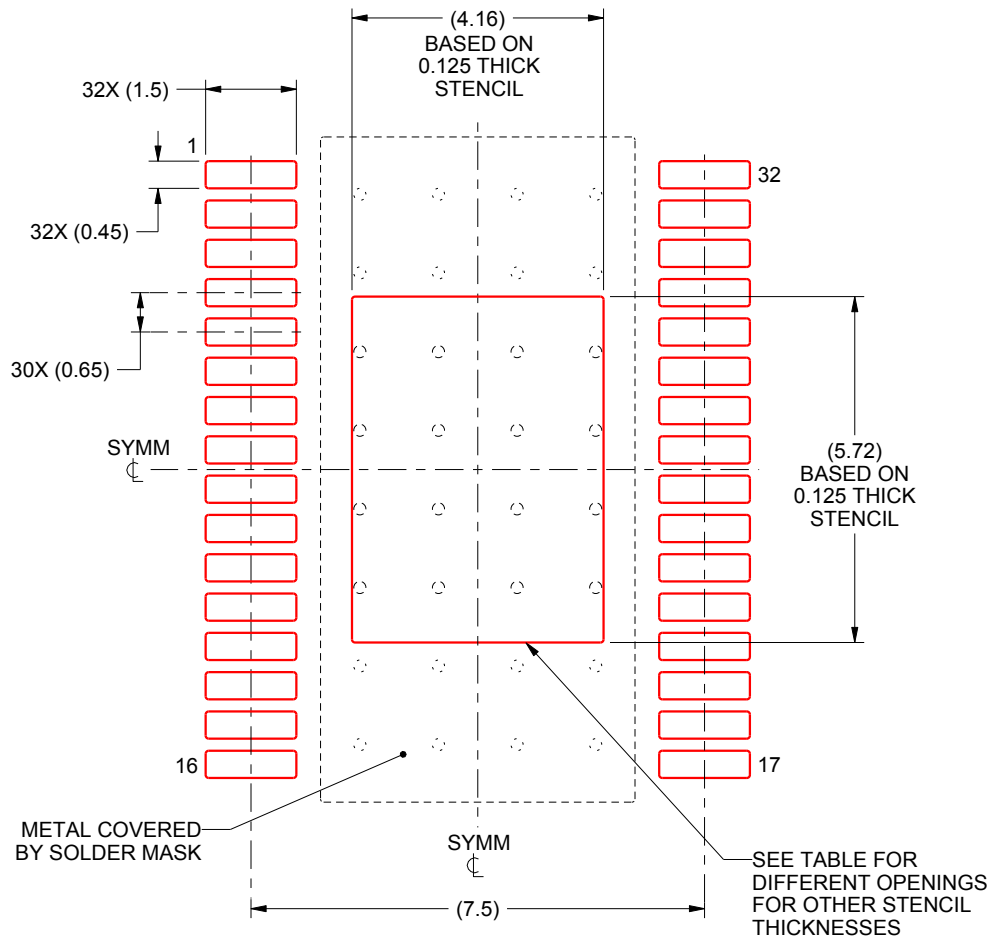
6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
8. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature numbers SLMA002 ([www.ti.com/lit/slma002](http://www.ti.com/lit/slma002)) and SLMA004 ([www.ti.com/lit/slma004](http://www.ti.com/lit/slma004)).
9. Size of metal pad may vary due to creepage requirement.

# EXAMPLE STENCIL DESIGN

DAP0032B

PowerPAD™ TSSOP - 1.2 mm max height

PLASTIC SMALL OUTLINE



**SOLDER PASTE EXAMPLE**  
EXPOSED PAD  
100% PRINTED SOLDER COVERAGE BY AREA  
SCALE:8X

| STENCIL THICKNESS | SOLDER STENCIL OPENING |
|-------------------|------------------------|
| 0.1               | 4.65 X 6.4             |
| 0.125             | 4.16 X 5.72 (SHOWN)    |
| 0.15              | 3.8 X 5.22             |
| 0.175             | 3.52 X 4.83            |

4222438/A 11/2015

NOTES: (continued)

10. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
11. Board assembly site may have different recommendations for stencil design.



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