TPS65381-Q1 Multirail Power Supply for Microcontrollers in Safety-Relevant Applications

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1 Device Overview

1.1 Features

- Qualified for Automotive Applications
- AEC-Q100 Qualified With the Following Results:
  - Device Temperature Grade 1: \(-40^\circ\mathrm{C}\) to \(+125^\circ\mathrm{C}\)
  - 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)
  - 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 TPS65381-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 TPS65381-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 TPS65381-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 TPS65381-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 TPS65381-Q1 monitoring and protection functions.

The TPS65381-Q1 device is offered in a 32-pin HTSSOP PowerPAD package.
1.4 Typical Application Diagram

Figure 1-1. Typical Application Diagram
Table of Contents

1 Device Overview .................................................. 1
   1.1 Features .................................................. 1
   1.2 Applications ............................................. 2
   1.3 Description ............................................... 2
   1.4 Typical Application Diagram ......................... 3
2 Revision History .................................................. 4
3 Pin Configuration and Functions ............................... 27
4 Specifications ...................................................... 29
   4.1 Absolute Maximum Ratings ............................ 29
   4.2 ESD Ratings .............................................. 29
   4.3 Recommended Operating Conditions ................. 30
   4.4 Thermal Information .................................... 31
   4.5 Electrical Characteristics ............................. 32
   4.6 Timing Requirements .................................... 36
   4.7 Switching Characteristics ............................. 37
   4.8 Typical Characteristics ................................. 38
5 Detailed Description ............................................. 39
   5.1 Overview .................................................. 39
   5.2 Functional Block Diagram .............................. 39
   5.3 Feature Description ..................................... 40
6 Application and Implementation .............................. 116
   6.1 Application Information ............................... 116
   6.2 Typical Application .................................... 116
   6.3 System Examples ........................................ 124
7 Power Supply Recommendations ............................... 129
8 Layout ............................................................. 129
   8.1 Layout Guidelines ....................................... 129
   8.2 Layout Example .......................................... 131
   8.3 Power Dissipation and Thermal Considerations .... 132
9 Device and Documentation Support ............................ 134
   9.1 Device Support .......................................... 134
   9.2 Documentation Support .................................. 134
   9.3 Receiving Notification of Documentation Updates.. 134
   9.4 Community Resources .................................... 134
   9.5 Trademarks ............................................... 134
   9.6 Electrostatic Discharge Caution ...................... 135
   9.7 Glossary .................................................. 135
10 Mechanical, Packaging, and Orderable Information ....... 135

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

Changes from Revision F (May 2016) to Revision G

- Changed the Features list for Supply rails to show output current instead of current limit. Added general current limit bullet in the FEATURES list.................................................................................. 1
- Added acronym definitions .......................................................................................... 1
- Changed recommended maximum voltage for VBATP and VBAT_SAFING in the Recommended Operating Conditions table ......................................................................................... 8
- Changed the PIN Function table descriptions to clarify device operation .................... 27
- Changed the max value for the charge-pump voltages from 52 V to lesser of VBATP + 16V or 52 V with footnote in the ABSOLUTE MAXIMUM RATINGS table ........................................................................ 29
- Changed M1.12 and M1.13 Sensor supply feedback and supply voltage by combining in M1.12 with conditions of use for the Sensor supply output and feedback voltage to match the sensor supply used. Changed the maximum to 18 V in the ABSOLUTE MAXIMUM RATINGS table .............................................................. 29
- Deleted M1.13 Sensor supply output voltage by combining with M1.12 in the ABSOLUTE MAXIMUM RATINGS table ............................................................................................................. 29
- Changed the table note for Absolute Maximum Ratings ............................................ 29
- Changed changed recommended operating condition descriptions for R1.1, R1.2 and R1.3 to make the operation of device more clear in the Recommended Operating Conditions .................................................................. 30
- Deleted recommended operating condition R1.3a and R1.3b, VBAT_SAFING impact to device operation was included in R1.2 and R1.3 to make the operation of device more clear in the Recommended Operating Conditions .................................................................. 30
- Changed link formats throughout document .................................................................. 30
- Changed recommended maximum voltage for VBATP and VBAT_SAFING in the Recommended Operating Conditions table ......................................................................................... 30
- Changed the Thermal Metric table and Derating Profile for Power Dissipation Based on High-K JEDEC PCB in the Thermal Information section .............................................................................. 31
- Changed application report link ..................................................................................... 31
- Changed the Derating Profile for the Power Dissipation in the Thermal Information table and the Power Dissipation and Thermal Considerations section ................................................................. 31
- Deleted R1.3b from the operating conditions in the Electrical Characteristics section since VBAT_SAFING condition R1.3b was merged with R1.2 in the Recommended Operating Conditions, Timing Requirements and

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Product Folder Links: TPS65381-Q1
Switching Characteristics sections .................................................................32
- Changed VDD6, POS 1.1 to only volts as units for consistency in the ELECTRICAL CHARACTERISTICS table. 32
- Deleted Hysteresis parameter from Tprot[1VDD] (POS 1.7) in the ELECTRICAL CHARACTERISTICS table. ..........32
- Changed VDD5, POS 2.1 to only volts as units for consistency in the ELECTRICAL CHARACTERISTICS table. ....32
- Changed POS 2.3 test condition to Load step 20% to 80% in 5 µs, with C[1VDD] = 5 µF for VDD5 output voltage dynamic parameter in the Electrical Characteristics table ......................................................32
- Changed PSRR to > 40 dB typical n the Electrical Characteristics for parameter 2.6 .............................................32
- Deleted Hysteresis parameter from Tprot[1VDD] (POS 2.13) in the ELECTRICAL CHARACTERISTICS table. ........32
- Changed all references of VDD3, 5 to VDD3/5 for consistency in the datasheet ......................................................32
- Added clarification on VDD6 current limit and duty cycle in the Electrical Characteristics section .....................32
- Added clarification on I[1VDD]min current limit in the Electrical Characteristics section ........................................32
- Changed VDD3/5, POS 3.1 to only volts as units for consistency in the ELECTRICAL CHARACTERISTICS table...33
- Changed POS 3.3 into 3.3a for 3.3 V setting and 3.3v for 5 V setting for VDD3/5 output voltage dynamic parameter in the Electrical Characteristics table .................................................................33
- Changed POS 3.3a and 3.3b test condition to Load step 20% to 80% in 5 µs, with C[1VDD] = 5 µF for VDD3/5 output voltage dynamic parameter in the Electrical Characteristics table ......................................................33
- Changed the minimum for POS 3.3a from 3.17 V to 3.15 V, VDD3/5 output voltage dynamic parameter in the Electrical Characteristics table .................................................................33
- Changed PSRR to > 40 dB typical n the Electrical Characteristics for parameter 3.6 .............................................33
- Deleted Hysteresis parameter from Tprot[1VDD] (POS 3.13) in the ELECTRICAL CHARACTERISTICS table. ........33
- Changed MAX value of VDD1[1VDD] (4.2) from 0.816 mV to 0.808 mV in the Electrical Characteristics table ........33
- Changed VDD1[1VDD] POS 4.2 to only volts as units for consistency in the ELECTRICAL CHARACTERISTICS table.33
- Changed VDD1dyn, POS 4.7, to typical due to dependency on external FET choice in the Electrical Characteristics table .................................................................33
- Changed the VDD1[1VDD]max, POS 4.8, to specific VDD1 output voltage range for test condition in the Electrical Characteristics table .................................................................33
- Changed PSRR to > 40 dB typical n the Electrical Characteristics for parameter 4.9 .............................................33
- Added clarification on I[1VDD]min load current at power up in the Electrical Characteristics section .................33
- Added clarification on I[1VDD]min load current limits in the Electrical Characteristics section ............................33
- Changed MVVSOUT1 min and max values from –25 and 25 to –35 and 35 in the ELECTRICAL CHARACTERISTICS table ........................................................................................................34
- Changed VSFB1, POS 5.3 to only volts as units for consistency in the ELECTRICAL CHARACTERISTICS table...34
- Changed Test Condition and PSRR to > 40 dB typical sensor supply to clarify the test in the Electrical Characteristics for parameters 5.6 .................................................................34
- Changed POS 5.11, VSOUT1[1VDD] for clarity of condition for output short circuit voltage range and changed maximum voltage to 18 V in the ELECTRICAL CHARACTERISTICS table .................................................................34
- Deleted Hysteresis parameter from Tprot[1VDD] (POS 5.13) in the ELECTRICAL CHARACTERISTICS table. ........34
- Changed I[1VDD]min, POS 5.14 minimum from 100 mA to 120 mA in the ELECTRICAL CHARACTERISTICS table 34
- Added clarification on I[1VDD]min load current and power dissipation in the Electrical Characteristics section ....34
- Changed min value for VDD3/5 UVhead to 155 mV from 170 mV for 3.3-V setting in the ELECTRICAL CHARACTERISTICS table POS 6.13 .................................................................35
- Changed VDD[1VDD] UV POS 6.16 units from ratio to mV for consistency in the ELECTRICAL CHARACTERISTICS table .................................................................35
- Changed VDD[1VDD] UV POS 6.17 MIN from 824 mV to 816 mV in the ELECTRICAL CHARACTERISTICS table ......35
- Changed VDD[1VDD] UV POS 6.17 units from ratio to mV for consistency in the ELECTRICAL CHARACTERISTICS table ........................................................................................................35
- Deleted VSOUT1 UV hysteresis parameter (typical), POS 6.19a in the ELECTRICAL CHARACTERISTICS table..35
- Deleted VSOUT1 UV hysteresis parameter (typical), POS 6.20a in the ELECTRICAL CHARACTERISTICS table..35
- Changed I[1IGN]rev parameter (7.4), -1, from MAX to MIN to match polarity in the ELECTRICAL CHARACTERISTICS table .................................................................35
- Changed I[1CAN]rev parameter (7.8), -1, from MAX to MIN to match polarity in the ELECTRICAL CHARACTERISTICS table .................................................................35
- Added clarification to POS 10.1, 10.2 and 10.3 by using pin names in parameter field instead of footnote and adding SEL[1VDD] pin to 10.1 and 10.2 in the ELECTRICAL CHARACTERISTICS table .................................................................36
- Changed t[1J]max from 2.5 ms to 5 ms in the Timing Requirements table .................................................................36
- Changed t[1J]max from 2.5 ms to 5 ms in the Timing Requirements table .................................................................36
- Changed t[1J]max from 2.5 ms to 5 ms in the Timing Requirements table .................................................................36
- Changed VBATP[1de] minimum from 200 µs to 180 µs and maximum from 280 µs to 260 µs in the Timing Requirements table for POS 6.7.................................................................36
• Changed minimum for t\textsubscript{WD\_pulse} in the ELECTRICAL CHARACTERISTICS table to 14.25 \(\mu\)s from 28 \(\mu\)s

• Deleted \textit{ERRx\_WDI\_deg}lich in the ELECTRICAL CHARACTERISTICS \(\mu\)s

• Changed min value for \(t\text{\textsubscript{VDI}}\) (13.3) to 85.7 ns in the ELECTRICAL CHARACTERISTICS table.

• Changed format of graphs

• Added clarification of operation in the VDD6 Buck Switch Mode Power Supply section

• Added a note to the VSOUT1 register clarifying VSOUT\_1\_EN through RESET state in the VSOUT1 Linear Regulator section

• Added note in the Wake-Up section to not send WR\_CAN\_STBY command while CANWU and/or IGN are still high.

• Changed WD\_FAIL\_CNT and WD\_FAIL\_CNT to WD\_FAIL\_CNT[2:0] throughout document

• Changed section heading levels from 5.4.1.1 through 5.4.1.20

• Changed the VCP17\_OV impact on device behavior in the Voltage Monitoring Overview table and the Internal Errors Signals table.

• Changed the VCP12\_OV the impact on device behavior in the Voltage Monitoring Overview table and the Internal Errors Signals table.

• Changed the MAIN\_BG and VMON\_BG UV and OV impact on device behavior in the Voltage Monitoring Overview table and the Internal Errors Signals table.

• Changed all \_UVN Signal Names in the Internal Error Signals table and Digital MUX section to Nxxx\_UV for consistency in datasheet for inverted logic signal names with N at the beginning of the name.

• Changed the signal name from VCP\_OV to VCP17\_OV for D1.7 in the Internal Error Signals table. Also changed the device state from Not changed for NRES and ENDRV to LOW, and State to STANDBY

• Changed the max deglitch for VDD5\_OT, VDD3/5\_OT and VSOUT1\_OT to 64us in the Internal Error Signals table

• Changed the naming convention of EN\_VDD5\_OT and EN\_VDD3/5\_OT to NMASK\_VDD5\_OT and NMASK\_VDD3/5\_OT to clarify option of these configuration bits throughout the datasheet

• Changed the description of VDD5\_OT in the Internal Errors Signals table for clarity

• Changed the VMON\_TRIM\_ERR deglitch time minimum from 15 to 5 \(\mu\)s and maximum from 30 to 10 \(\mu\)s in the Internal Error Signals table

• Changed the VMON\_TRIM\_ERR device state when flag is set to NRES = LOW from not changed, ENDRV = LOW from not changed and Device State to STANDBY from not changed in the Internal Error Signals table

• Added clarification footnote to VDD5\_CL internal signal in the Internal Error Signals table

• Changed Analog BIST Run States diagram to clarify operation in the Analog Built-In Self-Test section

• Changed ABIST\_UVOV\_ERR and ABIST\_OV\_UV to ABIST\_ERR throughout document

• Added notes to clarify considerations needed if a manual run of LBIST is done in DIAGNOSTIC or ACTIVE state in the Logic Built-In Self-Test (LBIST) section

• Added clarification in the Analog Built-In Self-Test (ABIST) and Logic Built-In Self-Test (LBIST) sections to clarify operation

• Changed paragraphs for VSOUT1, VDD6 and VDD3/5 overtemperature and current limit in the Junction Temperature Monitoring and Current Limiting section to clarify device operation

• Changed the descriptions in the Overtemperature and Overcurrent Protection Overview table to clarify device operation and made naming for thermal shutdown consistent to overtemperature

• Changed Section title to Diagnostic MUX and Diagnostic Output Pin (DIAG\_OUT)

• Added clarity to the DIAG\_OUT description in the Diagnostic Output Pin DIAG\_OUT section

• Added clarification to the SPI Interface Note for the use of the SPI in a bus while DIAG\_OUT MUX is enabled in the Diagnostic Output Pin DIAG\_OUT section

• Changed values and clarity of AMUX operation and added minimum output resistance in the Analog MUX Selection table

• Changed WDT\_ signal names to WD\_, WD\_RES\_EN to WD\_RST\_EN, NMASK\_VDD1\_OV to NMASK\_VDD1\_UV\_OV, and EN\_DRV to ENDRV throughout document

• Changed NRST\_EXT\_IN to NRST\_EXT\_IN for consistency with pin name

• Changed WDI\_Error to Error/WDI throughout document

• Changed the Watchdog Question (Token) Generation image in the Watchdog Timer Configuration for Question and Answer Configuration section

• Changed Figure for Watchdog Answer Calculation in the Question (Token) Generation section to remove FDBK[3:0] impact on Answer-x byte calculation

• Changed TOKEN\_ERR bit name to ANSWER\_ERR to more accurately describe the error the bit indicates throughout the datasheet

• Changed SEQ\_ERR status bit in Table WD\_STATUS Bits Versus Possible Watchdog Sequence Events section

• Added a note to clarify impact of changing SAFETY\_ERR\_PWM\_L or SAFETY\_ERR\_PWM\_H while the MCU ESM is running in the MCU Error Signal Monitor (MCU ESM) section

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- Added a note to clarify MCU ESM diagnostics in the MCU Error Signal Monitor (MCU ESM) section...
- Added clarification in the MCU Error Signal Monitor (MCU ESM) section...
- Added clarification for the LOW minimum and maximum duration time for the MCU ESM in the TMS570 Mode section...
- Changed the time range for HIGH and LOW pulse duration in PWM Mode section from 5 µs to 15 µs (minimum) and 1.28 ms to 3.8 ms (maximum) for consistency along with additional clarifications of operation...
- Changed clarification for HIGH and LOW pulse register minimum and maximum pulse timing for the MCU ESM in the PWM Mode section...
- Added a note to clarify MCU ESM to MCU synchronization in the MCU Error Signal Monitor (MCU ESM) PWM Mode section...
- Added note to clarify uncleared CFG_CRC_ERR impact to state diagram during DIAGNOSTIC state in the list of steps in the Device Configuration Register Protection section...
- Changed the Reset and Enable Circuit image to clarify operation...
- Changed section title from Device Controller State Diagram to Device Operating States and clarified device operating states operation...
- Changed the STANDBY, RESET, DIAGNOSTIC, ACTIVE and SAFE state text descriptions in their sections to clarify device operation...
- Added clarification in the RESET STATE list...
- Added clarification on BIST running on exit of RESET State to the RESET STATE section...
- Added note to clarify considerations needed if a manual run of LBIST is done in the DIAGNOSTIC state in the section...
- Added note to clarify considerations needed if a manual run of LBIST is done in the ACTIVE state in the section...
- Added note to clarify SAFE state time-out possible state transitions due to the SAFE state time-out in the section...
- Added the Power on Reset (NPOR) section to clarify device operation...
- Changed the STAT[2] and STAT[0] descriptions for SPI errors in the Device Status Flag Byte Response section...
- Added note to explain additional SPI diagnostics in the Device Status Flag Byte Response section...
- Added SPI Register Write Access Lock (SW_LOCK command) section in the Register Map section...
- Added clarification on which registers are re-initialized to default values after LBIST run in Register Map section...
- Added clarification to WR_CAN_STBY that this command is only valid with data 00h in the SPI Command Table...
- Deleted note "SPI WR update can occur only in the DIAGNOSTIC and ACTIVE states" for WR_SAFETY_BIST_CTRL command in the SPI Command Table...
- Changed SAFE_CFG_CRC to SAFETY_CFG_CRC throughout the datasheet for consistency of the register name...
- Changed register bit descriptions in the DEV_CFG2 Register table to clarify device operation...
- Added clarification on VDD5_UV operation when VDD5_EN = 0 in the VMON_STAT_2 Register...
- Added clarity to note on VDD5_ILIM bit description in the SAFETY_STAT_1 Register table...
- Changed the D[5] NRES_ERR, LBIST_ERR, ABIST_ERR, LBIST_RUN and ABIST_RUN register descriptions in SAFETY_STAT_3 Register...
- Added to the NRES_ERR description in the SAFETY_STAT_3 Register table...
- Changed the SPI_ERR[1:0] description in the SAFETY_STAT_4 Register table...
- Changed the LOCLK description in the SAFETY_STAT_4 Register table...
- Changed MCU_ERR bit description in SAFETY_STAT_4 Register table...
- Changed WD_ERR bit and NRES_ERR bit description in SAFETY_STAT_4 Register table to clarify operation...
- Deleted note "Write update can only occur in the DIAGNOSTIC and ACTIVE states." for WR_SAFETY_BIST_CTRL command in the SAFETY_BIST_CTRL Register...
- Changed SAFE_STATUS_2 to SAFETY_STATUS_2 for consistency in the datasheet...
- Changed NO_ERROR bit description to improve clarity in the SAFETY_CHECK_CTRL Register table...
- Changed ERROR_PIN_FAIL bit description in the SAFETY_ERR_STAT Register table...
- Changed to clarify the WD_FAIL bit description in the SAFETY_ERR_STAT Register table...
- Changed ERR_CNT to DEV_ERR_CNT[3:0] throughout datasheet for consistency in naming...
- Added clarification on the TOKEN_SEED[3:0] to the description in the WD_TOKEN_FDBCK Register table...
- Changed WD_FAIL_TH description in the WD_TOKEN_VALUE Register table for consistency...
- Changed added clarification on clearing of the ANSWER_ERR bit in the WD_STATUS Register table...
- Deleted "This bit is set to 1 when switching between the Trigger and Q&A Mode" and added clarification on how to clear the WD_CFG_CHG bit description in the WD_STATUS Register table...
- Changed TIME_OUT bit description in the WD_STATUS Register table to clarify how the bit is cleared...
- Added ANSWER_EARLY bit operation during trigger mode to the WD_STATUS Register table...
- Changed the description of VDD_EN in the SENS_CTRL Register table...
Changes from Revision E (July 2015) to Revision F

Page

- Added clarity to the PIN Function table descriptions .................................................. 27
- Added clarification in Recommended Operating Conditions that GND = PGND .................. 30
- Changed (1) maximum VBAT_SAFING to 36 V in the Recommended Operating Conditions table for parameter 1.3a to be consistent with VBAT .................................................. 30
- Added VBAT_SAFING input supply voltage range for normal operation RECOMMENDED OPERATING CONDITIONS table .................................................. 30
- Added clarification in statement for the ELECTRICAL CHARACTERISTICS table by adding VBAT_SAFING recommended operating range in addition to VBAT recommended operating range .................................. 32
- Changed description of parameter from Test Condition column to a footnote on the parameter in Electrical Characteristics table for parameters 1.2, 1.7, 2.1, 2.13, 3.1, 3.2, 3.13, 4.2, 5.1, 5.2, 5.3, 5.13, 6.4, 6.5, 6.7, 6.22, 6.23 .................................................................................................................. 32
- Added clarification on direct loading of VDD6 in the Electrical Characteristics table .................. 32
- Changed the Test Condition column to parameter description the ELECTRICAL CHARACTERISTICS table for 2.2, 3.1, 3.2, 5.1, 5.3a, 5.4, 9.3 .................................................................................................. 32
- Added clarification on resistor divider on regulation tolerance of VDD1 in the VDD1 section of the Electrical Characteristics table .............................................................. 33
- Deleted test condition from Tと思った電圧電流の範囲を適用する ........................................ 34
- Changed Test Condition for input to sensor supply to VSIN from VBAT in the Electrical Characteristics for parameters 5.6, 5.7, 5.8 .................................................................................. 34
- Changed the description for indication of VBAT_UV (6.1, 6.2) in the ELECTRICAL CHARACTERISTICS table. .................................................. 34
- Added the condition of VBAT = VBAT_SAFING to 6.1, 6.2, 6.3, 6.4, 6.5, 6.8, 6.9, 6.10, 6.11, 6.12, 6.13, 6.14, 6.15, 6.16, 6.17 in the ELECTRICAL CHARACTERISTICS table. .................................................. 34
- Added the condition of VBAT = VBAT_SAFING = 12 V to 7.1, 7.2, 7.3, 7.4, 7.7 and 7.8 the ELECTRICAL CHARACTERISTICS table .................................................. 35
- Changed test condition for the I IGN parameter (7.4) to 36 V, added clarification that VBAT = VBAT_SAFING = 36 V in the ELECTRICAL CHARACTERISTICS table .................................................. 35
- Changed test condition for the I CANWU parameter (7.7) to 36 V, added clarification that VBAT = VBAT_SAFING = 36 V in the ELECTRICAL CHARACTERISTICS table .................................................. 35
- Added clarification for Cpump and Cstore connections in the Charge Pump section of the ELECTRICAL CHARACTERISTICS table .................................................. 35
- Changed the Test Condition for NRES output low (parameter 9.1) level from 5mA to 2mA in the ELECTRICAL CHARACTERISTICS table .................................................. 36
- Added clarification in statement for the Timing Requirements table by adding VBAT_SAFING recommended operating range in addition to VBAT recommended operating range .................................................. 36

(1) The recommended maximum operating voltage for VBAT and VBAT_SAFING is listed as 34 V, just below the overvoltage detection thresholds for VBAT, VBAT_OVrise and VBAT_OVfall. TI recommends enabling overvoltage detection on VBAT (default is enabled, MASK_VBAT_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.
• Changed description of parameter from Test Condition column to a footnote on the parameter in the Timing Requirements table for parameters 6.7, 11.1 ........................................................ 36
• Changed to clarify IGNITION and CAN WAKE-UP parameters (7.6 and 7.9) in TIMING REQUIREMENTS table. ................................................................. 36
• Added clarification in statement for the Switching Characteristics table by adding VBAT_SAFING recommended operating range in addition to VBATP recommended operating range .......................................................... 37
• Added clarification of resistor divider feedback impact in the VDD1 Linear Regulator section. ................................................................. 41
• Changed pin name to VTRACK1 for pin determining tracking or non-tracking mode in VSOUT1 Linear Regulator section describing what occurs after completion of the VDDx ramp-up ................................................................. 42
• Added clarification on reserved bits (RSV) in the WDT_ANSWER Register ................................................................. 63
• Added note to explain conditions leading to inadvertent setting of SDO ERROR bit in the WDT_STATUS Register ................................................................. 63
• Added clarification on when the watchdog Markov chain and question counter are re-initialized in the Watchdog Sequence section ................................................................. 63
• Changed SAFETY_ERR_STATUS to SAFETY_ERR_STAT so all references to this register are consistent ................................................................. 63
• Added clarification on using the DIAG_EXIT_MASK bit for software debug to the end of the Watchdog Sequence section ................................................................. 63
• Changed DEV_STATE to DEV_STAT for Device Status in Register .......................................................................................................................... 63
• Added clarification on the watchdog fail counter and reset event requirements in the Watchdog Fail Counter, Status, and Fail Event section ................................................................. 63
• Added note in the Wake-Up section on how to wake up the device for systems that need to power up and down with the power supply and do not need IGN or CANWU ................................................................. 44
• Changed the Power-Up and Power-Down Behavior image for clarity .......................................................................................................................... 45
• Changed the VDD6 UV bit to D6 from D7 in the Voltage Monitoring Overview table ................................................................. 48
• Changed the name for VSOUT1 current-limit to VSOUT1_CL in the Internal Error Signals table ................................................................. 50
• Changed all references to the sensor supply to VSOUT1 for consistency .......................................................................................................................... 50
• Changed to clarify ABIST functionality in the Analog Built-In Self-Test (ABIST) section ................................................................. 62
• Changed LBIST coverage in the Logic Built-In Self-Test (LBIST) section ................................................................. 63
• Changed to clarify LBIST functionality in the Logic Built-In Self-Test (LBIST) section. ................................................................. 63
• Changed the impact on device behavior for VSOUT1 thermal protect and over current in the Thermal and Over Current Protection Overview table ................................................................. 55
• Changed the name for VSOUT1 current-limit to VSOUT1_CL in the Digital MUX Selection table ................................................................. 59
• Changed and clarified Watchdog timer text in the Watchdog Timer (WDT) section ................................................................. 60
• Changed the all references of ERROR/WDTI pin to ERROR/WDI pin for consistency ................................................................. 61
• Added clarification on the watchdog fail counter and reset event requirements in the Watchdog Fail Counter, Status, and Fail Event section ................................................................. 61
• Added the Watchdog Sequence section ................................................................. 62
• Changed and clarified the equations for watchdog WINDOW 1 and WINDOW 2 (tWCW and tWCW) timing Watchdog Sequence section ................................................................. 62
• Added the MCU to Watchdog Synchronization section ................................................................. 63
• Added note on TIME_OUT flag not latching during active SPI frame (nCS low) in the Trigger Mode (Default Mode) section ................................................................. 63
• Added clarification of the impact of a bad event on the watchdog sequence in the Trigger Mode Section and updated the images ................................................................. 63
• Added note on TIME_OUT flag not latching during active SPI frame (nCS low) in the Q&A Mode section ................................................................. 67
• Changed and clarified the watchdog in Q&A mode answer sequence requirements in the Watchdog Q&A Related Definitions section ................................................................. 68
• Changed the Watchdog Sequence in Q&A Mode image in the Watchdog Sequence in Q&A Mode section to update the Answer-3, Answer-2, Answer-1 requirements ................................................................. 69
• Added clarification on when the watchdog Markov chain and question counter are re-initialized in the Question (Token) Generation) section ................................................................. 69
• Added for clarification the Device Controller State Diagram ................................................................. 86
• Changed SAFETY_ERR_STATUS to SAFETY_ERR_STAT so all references to this register are consistent ................................................................. 88
• Added clarification on using the DIAG_EXIT_MASK bit for software debug to the end of the DIAGNOSTIC STATE section ................................................................. 89
• Added note to explain conditions leading to inadvertent setting of SDO ERROR bit in the Device Status Flag Byte Response section ................................................................. 93
• Added clarification on reserved bits (RSV) in the Register Map section ................................................................. 95
• Changed DEV_STATE to DEV_STAT for Device Status in Register table for consistency ................................................................. 97
• Deleted VSOUT1_ILIM in the SAFETY_STAT_1 Register table and made bit D3 a reserved bit (RSV) ................................................................. 102
• Changed VDD_3_5_SEL description in SAFETY_FUNC_CFG Register table ................................................................. 109
• Changed and clarified the WDT_TOKEN_FDBCK Register table ................................................................. 113
• Changed and clarified the WDT_WIN1_CFG Register table ................................................................. 113
• Changed and clarified the WDT_WIN2_CFG Register table ................................................................. 113
• Changed and clarified the WDT_TOKEN_VALUE Register table ................................................................. 114
• Changed and clarified the WDT_STATUS Register table ................................................................. 114
• Changed and clarified the WDT_ANSWER Register table ................................................................. 115
• Changed and clarified the Software Flowchart for Configuring and Synchronizing the MCU With the Watchdog in Q&A Mode flowchart ................................................................. 127
• Added the Software Flowchart for Configuring and Synchronizing the MCU With the Watchdog in Trigger Mode flowchart ................................................................. 128
• Added clarity for VBAT_SAFING in the Power Supply Recommendations section ................................................................. 129

Not Recommended for New Designs

Revision History 9
Changes from Revision D (May 2015) to Revision E

- Changed the maximum UV value for VDD1 from 0.97 to 0.98 in the Voltage Monitoring Overview table. Also updated the VDD output voltage information .......................................................... 48
- Changed the MAX value for VDD1_UVN from 0.97 to 0.98 in the Internal Error Signals table. Also updated the Device State When Flag Is Set cells for VDD1_UVN ........................................................................................................... 49
- Added clarification on the watchdog fail counter and reset event requirements in the Watchdog Enable Function image .................................................................................................................................................. 61
- Added clarification on the watchdog fail counter and reset event requirements in the Device Controller State Diagram........................................................................................................... 86

Changes from Revision C (March 2015) to Revision D

- Changed f_{2k VDD6} POS 1.5 minimum and maximum units from % to kHz for consistency in the ELECTRICAL CHARACTERISTICS table ................................................................. 32
- Changed MIN value of VDD1\_SENSE(4.2) from -2% to -1% in the Electrical Characteristics table ......................................................... 33
- Changed MAX value of VDD1 undervoltage level (6.16) from 0.97 to 0.98 in the Electrical Characteristics table ........................................... 35
- Changed description of un-used VDD1 regulator in the VDD1 Linear Regulator section .......................................................... 41
- Added clarification in the NMASK\_VDD1\_UV\_OV description in the DEV\_CFG1 Register table.............................................................. 98

Changes from Revision B (July 2014) to Revision C

- Changed Applications listed in the Applications Section ........................................................................................................... 2
- Deleted the nominal storage temperature value of 27°C ......................................................................................................................... 29
- Changed the Handling Ratings to ESD Ratings and moved T_\text{typ} into the Absolute Maximum Ratings table ........................................ 29
- Added clarification notes on output capacitance and ESR for VDD6 in the ELECTRICAL CHARACTERISTICS table ................................................................. 32
- Added the Typical Characteristics section ............................................................................................................................................. 32
- Added clarification of ESR needed on VDD6 output capacitance in the Functional Block Diagram .......................................................... 39
- Added clarification on effective output capacitance and ESR in the VDD6 Buck Switch Mode Power Supply section ............................... 39
- Added clarification on the IGN and CANWU pins with respect to transients Wake-Up section ........................................................................ 40
- Added start-up delay to VCP in the Power-Up and Power-Down Behavior ....................................................................................... 45
- Added SPI Interface Note on use of the SPI while DIAG\_OUT MUX is enabled in the Diagnostic Output Pin DIAG\_OUT section ........................................ 56
- Added clarification on the watchdog fail counter and reset event requirements in the WDT Fail Counter, WDT Status, and WDT Fail Event section ........................................................................................................... 61
- Changed the RT bits from 4.0 to 6.0 in the T_{WCW} calculation in the WDT1 Configuration With an External Trigger Input (Default Mode) section ........................................................................ 64
- Deleted the RT bits from 4.0 to 6.0 in the T_{WCW} calculation in the Watchdog Token-Response Sequence Run section and changed the second calculation from T_{WCW} to T_{WCW} ........................................... 68
- Changed WDT\_ANSW_CNT answer order in Set of 4-Bit WD Token Values and Corresponding 8-Bit Responses table ................................................................. 73
- Changed 4-bit watchdog answer counter to 2-bit watchdog answer counter (WDT\_ANSW_CNT) in Watchdog Token-Response Sequence Run and WDT\_STATUS Register Updates section ................................................................. 73
- Deleted logic BIST activated by MCU in SAFE state in the MCU Error Signal Monitor (MCU ESM) ............................................................................. 76
- Deleted permanently text for the CRC check in the Device Configuration Register Protection section ....................................................... 81
- Changed CRC check to return to step one for continuous check in the Device Configuration Register Protection section ........................................................................................................... 83
- Added clarification on the watchdog fail counter and reset event requirement in the Reset and Enable Circuit image ................................................................................................................................. 84
- Added or \text{POST\_RUN\_RST} = 1 & \text{IGN\_PWRL} = 1 & re-cranking on IGN to Global RESET Conditions text bubble of the Device Controller State Diagram image .................................................................................................................................................. 86
- Added clarification on watchdog fail counter text to the watchdog reset sub-bullet in the RESET STATE list ........................................ 87
- Changed status bit \text{STAT}[1] function in Device Status Flag Byte Response table ................................................................................................. 93
- Changed data for SW\_LOCK and SW\_UNLOCK commands, which were reversed in the SPI Command Table ............................................ 95
- Added clarification for watchdog failure in the SAFETY\_STAT\_2 Register table ................................................................................................................................. 103
Changes from Revision A (December 2013) to Revision B

- Added clarification for watchdog failure in the SAFETY_STAT_4_Register table .................................................. 105
- Added ERROR/WDI text to D[5] cleared to description in the SAFETY_ERR_STAT_Register table .......................... 110
- Added watchdog fail counter text to D[4] cleared to description in the SAFETY_ERR_STAT_Register table ............. 110
- Changed the calculation in the WDT_WIN1_CFG_Register table .............................................................................. 113
- Changed the calculation in the WDT_WIN2_CFG_Register table .............................................................................. 113
- Added the Typical Application section ...................................................................................................................... 116
- Clarified ESR needed on VDD6 output capacitance in the Typical Application Diagram ........................................... 117
- Added the System Examples section .......................................................................................................................... 124
- Added the Layout section ............................................................................................................................................. 129

Changes from Revision B to Revision C
Changed the default value of the NMASK_VDD1_UV_OV bit from 1 to 0 and the VDD1 bit value from 0 to 1 in the \textit{Electrical Characteristics} table.

- Added \textit{UV} to the NMASK_VDD1_OV name in the \textit{Designed Description} section.
- Moved block diagram into the \textit{Detailed Description} section and updated block colors.
- Changed the \textit{OV} max value for VDD3/5 (3.3 V) from 3.63 to 3.6 in the \textit{Voltage Monitoring Overview} table.
- Added \textit{nMASK} comments to the UV and OV impact on device behavior for VDD1 in the \textit{Voltage Monitoring Overview} table.

Moved the \textit{Internal Error Signals} table to after the \textit{Voltage Monitoring Overview} table in the \textit{Detailed Description} section.

- Changed the TYP value for the AVDD_UV signal from 3.81 to 3.6 in the \textit{Internal Error Signals} table. Also changed the device state from \textit{Not changed} for \text{NRES} and \text{ENDRV} to \text{iLOW}, and for State to \text{STANDBY}.
- Changed the TYP value for the VCP12_UV signal from 7.32 to 7.43 in the \textit{Internal Error Signals} table.
- Changed the TYP value for the VCP12_OV signal from 14 to 14.2 in the \textit{Internal Error Signals} table.
- Changed the typ value for VCP_OV from 20 to 21 in the \textit{Internal Error Signals} table.
- Changed NUV on signal names to UV throughout.
- Changed the MIN value for the LOCLK signal from 0.740:745 to 0.742 in the \textit{Internal Error Signals} table.
- Changed the \textit{OV} name bit that must be configured for \text{DIGITAL MUX} mode from \text{DIAG_MUX} to \text{MUX_CFG} in the \textit{Digital MUX (DMUX)} section.
- Deleted \textit{Watchdog function configuration} from the post-BIST-reset initialization list in the \textit{Logic Built-In Self-Test (LBIST)} section.
- Changed VCP voltage range from 0.8 to 5.5 to 0.8 to 4.
- Replaced the VSFB1 sensor-supply feedback voltage row wit the VSOUT1 sensor-supply voltage row in the \textit{Analog MUX Selection Table}.
- Changed VSFB1 divide ratio from 4 ± 0.5% to 1 in the \textit{Analog MUX Selection Table}. Also changed the Voltage Range from 1.226 V to 5 V ±2% to 2.5 V to 5 V.
- Changed the Voltage Range / Accuracy value for both MAIN_BG and VMON_BG from 1.226 to 2.5 V in the \textit{Analog MUX Selection table}.
- Changed the name bit that must be configured for \text{DIGITAL MUX} mode from \text{DIAG_MUX} to \text{MUX_CFG} in the \textit{Digital MUX (DMUX)} section.
- Deleted \textit{Bits INT\_CON[2:0]} in \textit{DIAG\_CFG\_CTRL} register must be set to 111 list item from the \textit{SDO} diagnostic check sequence in the \textit{MUX interconnect check section}.
- Changed the RT bits from 4:0 to 6:0 in the $T_{\text{DCW}}$ calculation in the \textit{WDTI Configuration With an External Trigger Input (Default Mode) section}.
- Deleted the \textit{CLOSE} window note from the \textit{Possible Cases for Bad Watchdog Event} image and updated the image.
- Added +1 to the duration time program calculations in the \textit{Watchdog Token-Response Sequence Run} section and changed the second calculation from $T_{\text{DCW}}$ to $T_{\text{DCW}}$.
- Changed the filter time for the \textit{ERROR/WDI} deglitch from 15-s to 15-µs in the \textit{MCU Error Signal Monitor (MCU ESM)} section.
- Changed the low-pulse duration increment from 15-s to 15-µs in the \textit{PWM Mode} section.
- Changed the \textit{Reset and Enable Circuit} figure to reflect overtemperature behavior.
- Added _UV to the \textit{NMASK\_VDD1\_OV} name in the \textit{Reset and Enable Circuit} image.
- Added _UV to the \textit{NMASK\_VDD1\_OV} name in \textit{DIAGNOSTIC} and \textit{ACTIVE state} text box of the \textit{Device Controller State Diagram} image.
- Deleted WDT failure text from the first list item in the \textit{SAFE State} section.
- Moved all of the registers into one \textit{Register Map} section.
- Changed D0 from 1 to 0 in the \textit{DEV\_REV Register} table.
- Changed D1 and D0 from 0 to X in the \textit{DEV\_STATE Register} table.
- Changed the deglitched minimum time from 7.7 to 7.5 for the IG bit description in the \textit{DEV\_STATE} register.
- Changed D7 from RSV and 1 to VDD3_5_SEL and X in the \textit{DEV\_CFG1 Register} table.
- Changed D6 from nMASK\_VDD\_UV and 1 to nMASK\_VDD\_UV\_OV and 0 in the \textit{DEV\_CFG1 Register} table.
- Changed the default value of the NMASK\_VDD1\_UV\_OV bit from 1 to 0 and the VDD1 bit value from 0 to 1 in the \textit{DEV\_CFG1 Register}.
Changes from Original (May 2012) to Revision A

- Changed bit D5 name from MASK_VBAT_OV to MASK_VBATP_OV in the DEV_CFG2 Register table ........................................ 99
- Added after SPI read access from the clear to 0 description of each bit in the VMON_STAT_1 Register ........................................ 100
- Added after SPI read access from the clear to 0 description of each bit in the VMON_STAT_2 Register ........................................ 101
- Added after SPI read access from the clear to 0 description of each bit in the SAFETY_STAT_1 Register ............................................... 102
- Added description to bit D[4] when set to one when the device is the DIAGNOSTIC state .......................................................... 103
- Updated the WD_RST_EN bit description for setting this bit to 0 in the SAFETY_STAT_3 register table ............................................. 104
- Updated cleared to 0 description of the LBIST_ERR bit in the SAFETY_STAT_3 register ......................................................... 104
- Updated cleared to 0 description of each bit in the DIAGNOSTIC state description ................................................................. 104
- Updated description to internal NPOR from the LOCLK bit description in the SAFETY_STAT_4 Register ........................................ 105
- Added bit D7 and bit D6 from 1 to 0 in the SAFETY_ERR_CFG Register table ................................................................. 106
- Added description to bit D[4] when set to one when the device is the DIAGNOSTIC state .......................................................... 103
- Added description to bit D[4] when set to one when the device is the DIAGNOSTIC state .......................................................... 103
- Added name of protected registers in the CRG_CRC_EN bit description in the SAFETY_CHECK_CTRL Register ........................................ 108
- Changed monitored to not monitored in the NO_ERROR bit description for setting this bit to 1 in the SAFETY_CHECK_CTRL Register ........................................ 108
- Changed CTRL to CFG in the read and write commands of the SAFETY_FUNC_CFG Register ........................................... 109
- Changed D7 from 0 to 1 in the SAFETY_FUNC_CFG Register table ................................................................. 109
- Changed D4 from 1 to 0 in the SAFETY_FUNC_CFG Register table ................................................................. 109
- Changed D0 from 0 to X in the SAFETY_FUNC_CFG Register table ................................................................. 109
- Changed 15 seconds to 15 µs in the SAFETY_ERR_PWM_H Register table description ..................................................... 110
- Changed the time reference amount from 15 s to 15 µs in the PWML[7:0] bit description for when ERR_CFG is set to 0 in the SAFETY_ERR_PWM_L Register ........................................... 111
- Changed 5 seconds to 5 µs in the SAFETY_ERR_PWM_H Register table description ..................................................... 111
- Changed 15 seconds to 15 µs in the SAFETY_ERR_PWM_H Register table description ..................................................... 111
- Added Note: With configuration 001 setting for INT_OUT[2:0] bits text from the SPI_SDO description in the DIAG_CFG_CTRL Register. Also changed the 111 description of the INT_OUT[2:0]] from controlling the state of the SPI_SDO output buffer to Not applicable ........................................ 112
- Included bit 2 to all WDT_FAIL_CNT bit references .................................................................................................................. 114
- Changed command for the WDT_ANSWER Register from Read to Write ............................................................................................ 114
- Changed the default setting of VSOUT1_EN from 1 to 0 in the SENS_CTRL Register table ..................................................... 115
- Changed Moved the Application Information section into the Application and Implementation section and added product folder references ........................................ 117
DESCRIPTION

- Changed to data manual template to include table of contents and section numbers
- Added ADC, VDD6, to Typical Application Diagram
- Changed PGND type from input to ground in PIN FUNCTIONS table
- Changed POS numbers in ABSOLUTE MAXIMUM RATINGS table for adjustments
- Changed POS numbers in ABSOLUTE MAXIMUM RATINGS table for adjustments
- Added Charge-pump overdrive voltage to the ABSOLUTE MAXIMUM RATINGS table
- Deleted DMUX0 from Logic I/O voltage list (M1.15) in the ABSOLUTE MAXIMUM RATINGS table
- Deleted \( T_J \) min value of \(-40 \) from ABSOLUTE MAXIMUM RATINGS table
- Changed unit for CDM on corner pins (750) from kV to V in the ABSOLUTE MAXIMUM RATINGS table
- Deleted VDDIO internal pullup diode note from the RECOMMENDED OPERATING CONDITIONS table
- Added values to the current consumption parameter in the RECOMMENDED OPERATING CONDITIONS table...
- Changed condition statement for the ELECTRICAL CHARACTERISTICS table by adding \( T_A \) over junction temperature with up to 150°C
- Added VDD6ripple parameter to the ELECTRICAL CHARACTERISTICS table
- Added VDD6 output voltage to \( I_{VDD6} \) parameter (A1.2) in the ELECTRICAL CHARACTERISTICS table
- Changed example to \( V_{dropout} \) (A1.3) test condition in the ELECTRICAL CHARACTERISTICS table
- Changed \( I_{VDD6,\, trim} \) parameter description from current-limit to peak current in the ELECTRICAL CHARACTERISTICS table...
- Changed A1.5 from \( F_{SW,\, VDD6} \) switching frequency to \( F_{DC,\, VDD6} \) clock frequency, added note, and deleted test condition from the ELECTRICAL CHARACTERISTICS table. Also added test condition...
- Changed test condition for DC \( V_{DD5} \) parameter (A1.6) from VBATP \( > 7 \) V to \( 0 < I_{VDD6} < 1.3 \) A in the ELECTRICAL CHARACTERISTICS table...
- Added Hysteresis parameter, min and max values to \( T_{prot,\, VDD6} \) (A1.7) in the ELECTRICAL CHARACTERISTICS table. Changed test condition from Global shutdown to Protection of VDD6, shared with VDD3/5 thermal protection. For both \( T_{prot,\, VDD5} \) parameters...
- Added Hysteresis parameter, min and max values to \( T_{prot,\, VDD6} \) (2.13) in the ELECTRICAL CHARACTERISTICS table. Changed test condition from VDD5 switch-off to Protection of VDD5. In case of detected over-temperature, only VDD5 will be switched-off for both \( T_{prot,\, VDD5} \) parameters...
- Added VDD3/5 end-value to test condition for the dVDD35/dt parameter (3.11) in the ELECTRICAL CHARACTERISTICS table...
- Added Hysteresis parameter, min and max values to \( T_{prot,\, VDD3} \) (3.13) in the ELECTRICAL CHARACTERISTICS table. Changed test condition from Global shutdown to Protection of VDD3/5, treated as global thermal shutdown (shutdown for all regulators) for both \( T_{prot,\, VDD3} \) parameters...
- Added test condition to the dVDD1/dt parameter (A4.14) in the ELECTRICAL CHARACTERISTICS table...
- Added VSOUT1 text to test condition for VSOUT1 parameter (5.1) in the ELECTRICAL CHARACTERISTICS table...
- Changed MVVSOAT1 min and max values from \(-15 \) and 15 to \(-35 \) and 35 in the ELECTRICAL CHARACTERISTICS table...
- Added min and max values for the Threshold for tracking/non-tracking parameter in the ELECTRICAL CHARACTERISTICS table...
- Added Hysteresis parameter, min and max values to \( T_{prot,\, VSOAT1} \) (5.13) in the ELECTRICAL CHARACTERISTICS table. Changed test condition from VSOAT1 switch-off to Protection of Sensor Supply. Only VSOUT1 switch-off for both \( T_{prot,\, VSOUT1} \) parameters...
- Changed min and max values for VBATP \( _{OV,\, max} \) parameter from 29.5 and 32.5 to 34.7 and 36.7 (respectively) in the ELECTRICAL CHARACTERISTICS table. Also added test condition...
- Deleted VBATP \( _{OV,\, hyps} \) (POS 6.6) from the ELECTRICAL CHARACTERISTICS table...
- Changed min and max values for VBATP \( _{OV,\, max} \) parameter from 29 and 32 to 34.4 and 36.3 (respectively) in the ELECTRICAL CHARACTERISTICS table. Also added test condition...
- Added Hysteresis parameter, min and max values to VDD5 \( _{OV} \) (6.8) in the ELECTRICAL CHARACTERISTICS table...
- Changed max value for VDD5 \( _{OV} \) from 5.5 to 5.45 in the ELECTRICAL CHARACTERISTICS table...
- Added Hysteresis parameter, min and max values to VDD5 \( _{OV} \) (6.10) in the ELECTRICAL CHARACTERISTICS table...
- Changed min value for VDD3/5 \( _{UV} \) with test condition of 3.3-V setting (undervoltage) from 2.97 to 3 in the ELECTRICAL CHARACTERISTICS table...
- Changed max value for VDD3/5 \( _{UV} \) with test condition of 5-V setting (undervoltage) from 4.8 to 4.85 in the ELECTRICAL CHARACTERISTICS table...
- Added Hysteresis parameter for 3.3 and 5 V settings, min and max values to VDD5/3 \( _{UV} \) (6.12) in the...
ELECTRICAL CHARACTERISTICS table.

- Changed max value for VDD3_5_OV with test condition of 3.3-V setting from 3.63 to 3.6 in the ELECTRICAL CHARACTERISTICS table.
- Added Hysteresis parameter for 3.3 and 5 V settings, min and max values to VDD3_5_OV (6.14) in the ELECTRICAL CHARACTERISTICS table.
- Added Hysteresis parameter, min and max values to VDD1_UV (6.16) in the ELECTRICAL CHARACTERISTICS table. Changed test condition from Sensed on VDD1_SENSE pin to Sensed on VDD1_SENSE pin. Relative thresholds are with respect to nominal 800-mV VDD1_SENSE (Pos 4.2) for both VDD1_UV parameters.
- Added Hysteresis parameter, min and max values to VDD1_OV (6.17) in the ELECTRICAL CHARACTERISTICS table. Changed test condition from Sensed on VDD1_SENSE pin to Sensed on VDD1_SENSE pin. Relative thresholds are with respect to nominal 800-mV VDD1_SENSE (Pos 4.2) for both VDD1_OV parameters.
- Added Hysteresis parameter, min and max values to VSOUT1_UV (6.19) in the ELECTRICAL CHARACTERISTICS table. Changed test condition from Sensed on VSFB1 pin to Sensed on Vsfb1 pin. Relative thresholds are: for both VSOUT1_UV parameters.
- Added Hysteresis parameter, min and max values to VSOUT1_UV (6.20) in the ELECTRICAL CHARACTERISTICS table. Changed test condition from Sensed on VSFB1 pin to Sensed on VSFB1 pin. Relative thresholds are: for both VSOUT1_UV parameters.
- Added Hysteresis parameter, min and max values to VDD6_UV (6.22) in the ELECTRICAL CHARACTERISTICS table. Also added test condition for both VDD6_UV parameters.
- Added Hysteresis parameter, min and max values to VDD6_OV (6.23) in the ELECTRICAL CHARACTERISTICS table. Also added test condition for both VDD6_OV parameters.
- Added test condition to the tIGN parameter in the the ELECTRICAL CHARACTERISTICS table (7.4)
- Changed I_CAN parameter (7.7) to I_CANWU and added test condition to the ELECTRICAL CHARACTERISTICS table.
- Changed I_CAN_rev (7.8) max value from 1 to −1 in the ELECTRICAL CHARACTERISTICS table.
- Added test condition for ICSP (8.2) in the ELECTRICAL CHARACTERISTICS table.
- Added min and max values for fCP (8.3) in the ELECTRICAL CHARACTERISTICS table.
- Deleted min value of 11 for the Rdsn_ENDRV_NRES (9.2a) parameter in the ELECTRICAL CHARACTERISTICS table.
- Added input and logic 1 to the VENDRV_NRES_TH parameter (9.5) in the description in the ELECTRICAL CHARACTERISTICS table.
- Deleted max value from 500 to 450 for the VENDRV_NRES_TH (9.5) parameter in the ELECTRICAL CHARACTERISTICS table.
- Added note reference and test condition to the VDIGIN_LOW parameter (10.2) in the ELECTRICAL CHARACTERISTICS table.
- Added note reference and test condition to the VDIGIN_HYST parameter (10.3) in the ELECTRICAL CHARACTERISTICS table. Also added parameter name.
- Changed 10.4 from empty to the RDIAGOUT_AMUX parameter to the ELECTRICAL CHARACTERISTICS table.
- Added pin note to the VDIGOUT_HIGH parameter (10.5) in the ELECTRICAL CHARACTERISTICS table.
- Added pin note to the VDIGOUT_LOW parameter (10.6) in the ELECTRICAL CHARACTERISTICS table.
- Added min and max values for tTESTEXT(9.4a) in the ELECTRICAL CHARACTERISTICS table.
- Added tWPD_pulse parameter to the ELECTRICAL CHARACTERISTICS table.
- Added for MCU error signal monitor to the tERROR_WDI_deglitch parameter (12.1) in the ELECTRICAL CHARACTERISTICS table.
- Changed max value for the tERROR_WDI_deglitch parameter (12.1) from 15.75 to 16.25 in the ELECTRICAL CHARACTERISTICS table.
- Added two test conditions to the fSPI parameter (13.1) and removed the single max value of 8 to replace it with the max value for each condition in the ELECTRICAL CHARACTERISTICS table.
- Added two test conditions to the tSPI parameter (13.2) and removed the single min value of 125 to replace it with the min value for each condition in the ELECTRICAL CHARACTERISTICS table.
- Changed max value for tMSP(13.7) to min value in the ELECTRICAL CHARACTERISTICS table. Also changed parameter description from rising edge to falling edge of SCLK.
- Changed min value from 250 to 788 for the tSLIC parameter (13.10) in the ELECTRICAL CHARACTERISTICS table. Also added NCS high text to parameter description.
- Added test condition to the fSysclk Parameter (11.1) in the ELECTRICAL CHARACTERISTICS table.
- Added SDO transition from tri-state to tS1 Parameter (13.6) description in the ELECTRICAL CHARACTERISTICS table.
- Changed max value of tS1 from 30 to 53.3 in the ELECTRICAL CHARACTERISTICS table.
Revision History

Not Recommended for New Designs

(-) Replaced Old Reference with New Reference
(-) Removed Old Reference
(-) Changed Old Reference to New Reference
(-) Changed Old Description to New Description
(-) Changed Old Parameter to New Parameter
(-) Changed Old Section to New Section
(-) Changed Old Table to New Table
(-) Changed Old Graph to New Graph
(-) Changed Old Diagram to New Diagram
(-) Changed Old Figure to New Figure

- Changed max value of $t_{pd}$ from 30 to 85.7 in the ELECTRICAL CHARACTERISTICS table. parameter description from falling edge to rising edge of SCLK.
- Changed $t_{pd}$ parameter (13.11) description from Hi-Z state to tristate in the ELECTRICAL CHARACTERISTICS table.
- Changed max value of $t_{pd}$ (13.11) from 15 to 25 in the ELECTRICAL CHARACTERISTICS table.
- Added $t_{pd}$ to right side of SPI Timing Parameters diagram.
- Added the SPI SDO Buffer Source/Sink Current graph after the ELECTRICAL CHARACTERISTICS table.
- Changed block diagram.
- Added condition for when the N-channel MOSFET turns on to the second paragraph in the VDD6 Buck Switch Mode Power Supply section.
- Deleted clearing out of SAFETY_STAT from re-enable VDD5 paragraph and changed SENS_CTRL bit from 4 to D4 in the VDD5 Linear Regulator section.
- Added the default VDD1 paragraph to the end of the VDD1 Linear Regulator section.
- Added sentence to the first paragraph in the VSOUT1 Linear Regulator section describing what occurs after completion of the VDDx ramp-up.
- Changed tracking offset from ±15 to ±35 in the VSOUT1 Linear Regulator section.
- Added SPI command setting to the seventh paragraph in the section.
- Added DIAGNOSTIC state text to the Wake-Up section.
- Added second paragraph in the Wake-Up section: changed edge-sensitive to level-sensitive and pulse duration to de-glitch time.
- Added during a power-up event to the Reset Extension section and removed VDD1 from the description.
- Deleted open-connect and RESET state sentence from the last paragraph in the Reset Extension section.
- Added notes to the IGN Power Latch and POST-RUN Reset image in the Power-Up and Power-Down Behavior section.
- Deleted reset driver from ENDRV bullet in the Safety Functions and Diagnostics Overview section.
- Added the Voltage Monitoring Overview table and table reference to the Voltage Monitor (VMON) section.
- Added the Internal Error Signals table.
- Deleted loss-of-power note and cleared-latched bullet from the clock failure list in the Loss-of-Clock Monitor (LCMON) section.
- Added SPI register bit to the latched bullet in the clock failure list in the Loss-of-Clock Monitor (LCMON) section.
- Added ABIST case paragraphs following the Analog BIST Run States image.
- Moved Logic Built-In Self-Test (LBIST) section from after DMUX tables and added initialized registers list.
- Deleted VDD5 and VSOUT1 supplies from first paragraph of the Junction Temperature Monitoring and Current Limiting section.
- Added VSOUT1 supplies paragraph to the Junction Temperature Monitoring and Current Limiting section.
- Added
- Deleted STANDBY State text from the Junction Temperature Monitoring and Current Limiting section and changed to regulated supplies. Also added ENDRV pin.
- Changed third paragraph of the Junction Temperature Monitoring and Current Limiting section to include NRES asserted low and VDD5 reenable.
- Added Thermal and Overcurrent Protect Overview table and table reference to the Junction Temperature Monitoring and Current Limiting section.
- Added analog and digital signals and notes to the Diagnostic Output Pin DIAG_OUT image in the Diagnostic Output Pin DIAG_OUT section.
- Added added disabled state description for the DIAG_OUT pin in the last paragraph of the Diagnostic Output Pin DIAG_OUT section.
- Added accuracy and corresponding table note to the voltage range column in the Analog MUX Selection table.
- Added ± percentage to the divide ratio values (except for MAIN_BG and VMON_BG) the Analog MUX Selection table.
- Changed the DIAG_MUX_SEL column and header in the Analog MUX Selection table.
- Added the max output resistance column to the Analog MUX Selection table.
- Changed VSFB1 divide ratio from 1 to 4 in the Analog MUX Selection Table.
- Added the voltage/signal name for signal number A.7 from BG1 to MAIN_BG in the Analog MUX Selection table.
- Added additional text and note to further explain the Analog MUX Selection Table.
- Added second paragraph to the Digital MUX (DMUX) section.
- Added diagnostic check text, Diagnostic MUX Output state (by MUX_OUT bit), and MUX interconnect check section after DMUX tables.
- Changed the Watchdog Enable Function image in the WDT Fail Counter, WDT Status, and WDT Fail Event section.
• Added watchdog fail counter text after the Watchdog Status for Fail Counter Value Range table.......................... 61
• Changed trigger events paragraph (third) in the WDTI Configuration with External Trigger Input (Default Mode) section .................................................. 63
• Added SPI register names and DIAGNOSTIC state to the open and close window programming sentence in the WDTI Configuration with External Trigger Input (Default Mode) section .................................................. 64
• Added the WDTI window sequencing and SPI SW_LOCK paragraphs in the WDTI Configuration with External Trigger Input (Default Mode) section .................................................. 64
• Added the WDTI rising edge paragraph in the WDTI Configuration with External Trigger Input (Default Mode) section and added TWD_pulse filter time paragraph .................................................. 64
• Added image to the WDTI Configuration with External Trigger Input (Default Mode) section .................................................. 65
• Added image to the WDTI Configuration with External Trigger Input (Default Mode) section .................................................. 66
• Deleted ASIC reference in the first paragraph of the Watchdog Question /and Answer Configuration Through SPI section .................................................. 67
• Added starts a new watchdog token-response sequence run to the no-response event description in paragraph four of the Watchdog Question /and Answer Configuration Through SPI section .................................................. 67
• Added 4-bit word bullet to the Watchdog Token Request definition list in the Watchdog-Timer-Related SPI Event Definitions section .................................................. 67
• Added 32-bit word bullet to the Watchdog Token Timer Request definition list in the Watchdog-Timer-Related SPI Event Definitions section .................................................. 68
• Added Watchdog Token-Response Sequence Run section to replace the Watchdog Timer Configuration for Question and Answer Configuration section .................................................. 68
• Changed the WDT Token and Response Sequence Run image in the Watchdog Token-Response Sequence Run section .................................................. 69
• Added the 4-bit question paragraph to the Watchdog Token Value Generation (or Watchdog Question Generation) section .................................................. 69
• Added the Watchdog TOKEN Generation image and following text in the Watchdog Timer Configuration for Question and Answer Configuration section .................................................. 70
• Added Answer Comparison and Reference Answer section .................................................. 72
• Changed WDT answer column header names - switched response 0 and response 3, switched response 2 and response 1 in the Set of 4-Bit WD Token Values and Corresponding 8-Bit Responses table. Added token registerDevice Configuration Register Protection name and value to token column. .................................................. 73
• Added Watchdog Token-Response Sequence Run and WDT_STATUS Register Updates section .................................................. 73
• Added activation and deactivation paragraph in the MCU Error Signal Monitor (MCU ESM) section .................................................. 75
• Added DIAGNOSTIC and ACTIVE state paragraph in the MCU Error Signal Monitor (MCU ESM) section .................................................. 76
• Added deglitched and synchronized paragraph in the MCU Error Signal Monitor (MCU ESM) section .................................................. 76
• Added ERROR/WDI pin implementation text in the MCU Error Signal Monitor (MCU ESM) section .................................................. 76
• Added the first paragraph in the PWM Mode section and added the detect and no detect statements .................................................. 78
• Added monitoring lists to the PWM Mode section .................................................. 78
• Changed register setting text for the ERROR_PIN_FAIL bit from error-pin signaling failure to system clock detection to the PWM Mode section .................................................. 80
• Added CFG_CRC_ERR flag text to the Device Configuration Register Protection section .................................................. 81
• Changed CRC-8 polynomial from X8 + X7 + X6 + X4 + X2 + 1 to X8 + X2 + X1 + 1 in the Device Configuration Register Protection section .................................................. 81
• Added 64-bit string text and protected registers list in the Device Configuration Register Protection section .................................................. 81
• Added CRC Bus Structure table in the Device Configuration Register Protection section .................................................. 82
• Added CRC calculation text, image, and table in the Device Configuration Register Protection section .................................................. 82
• Added EEPROM CRC check and list of steps in the Device Configuration Register Protection section .................................................. 83
• Changed the Reset and Enable Circuit image in the Enable and Reset Driver Circuit section .................................................. 84
• Added ENDRY pulled low paragraph to the Enable and Reset Driver Circuit section .................................................. 84
• Changed timing-response diagram description from RESET condition to any VDDx UV or OV condition in the Enable and Reset Driver Circuit section .................................................. 85
• Added RESET condition image in the Enable and Reset Driver Circuit section and replaced it with the any VDDx UV or OV condition image .................................................. 85
• Changed Device Controller State Diagram image .................................................. 86
• Added Internal NPOR (power-on reset) bullet item in the STANDBY STATE section .................................................. 87
• Changed IGN and CANWU driven low bullet item to deglitched IGN, IGN_PWRL, and CANWU_L with values in the STANDBY STATE section .................................................. 87
• Added device error count text to the SAFE state bullet in the RESET STATE list .................................................. 87
• Deleted the ACTIVE state bullet in the RESET STATE list .................................................. 87
• Added VDD5 sub-bullet in the RESET STATE list .................................................. 87
Not Recommended for New Designs

- Added watchdog fail counter text to the watchdog reset sub-bullet in the \textit{RESET STATE} list .................................................. 87
- Added ramping up sub-bullet to the first item in the \textit{RESET STATE} list ................................................................. 88
- Added \textit{RESET State} transition paragraph to the \textit{RESET STATE} list ................................................................. 88
- Added NRES pulled up to the \textit{Enters \textit{RESET} state} bullet in the \textit{DIAGNOSTIC STATE} list ........................................ 88
- Added VSOUT1, watchdog and ERROR/WDI, watchdog failure counter, and ENDRV pin bullets in the \textit{DIAGNOSTIC STATE} list .................................................. 88
- Added DIAG_EXIT\_MASK and DIAG\_EXIT text to the end of the \textit{DIAGNOSTIC STATE} list ........................................ 89
- Changed two bullets in the \textit{ACTIVE STATE} list and added three additional bullets ....................................................... 89
- Added uncontrolled transition sub-bullet to the enters \textit{DIAGNOSTIC state} bullet in the \textit{SAFE STATE} list ................. 90
- Added \textit{ACTIVE} state read-back error, stays in Safe state, NRES, and VDDx bullets in the \textit{SAFE STATE} list ................. 90
- Added \textit{STATE TRANSITION PRIORITIES} section .............. 91
- Deleted \textit{Enters from \textit{RESET}, \textit{DIAGNOSTIC}, or \textit{ACTIVE} state after \textit{ABIST} or \textit{LBIST} failure} bullet from the SPI 4-pins list in the \textit{SPI Interface} section ........................................... 92
- Added minimum time sentence to paragraph after the \textit{SPI Command \textit{Transfer Phrase} table} ........................................ 92
- Added paragraph describing the possibility of mixing two access modes in the \textit{SPI Data-Transfer Phrase} section .................. 93
- Added minimum time sentence to paragraph after the \textit{SPI Data-Transfer Phrase} table ........................................... 93
- Added \textit{Device Status Flag Byte Response} table ................... 95
- Changed \textit{DEG\_REV Register} table ................................. 95
- Changed \textit{D0} from 0 to 1 in the \textit{DEG\_REV Register} table .................................................................................. 96
- Changed \textit{D0} from 0 to 1 in the \textit{DEG\_REV Register} table .................................................................................. 96
- Changed \textit{D0} from 0 to 1 in the \textit{DEG\_REV Register} table .................................................................................. 96
- Changed \textit{EN\_VDD3/5\_OT} description by removing extra text after \textit{set to 1} and adding two more bullets in the \textit{DEG\_CFG2 Register} table .................................................. 97
- Changed \textit{read/write} text for \textit{D[3:0]} in the \textit{DEG\_CFG2 Register} table .................................................. 99
- Changed \textit{AVDD\_VMON\_ERR} description from error status to power-good status in the \textit{VMON\_STAT\_1 Register} table .................................................. 99
- Changed \textit{set to 1} text of \textit{D[1]} in the \textit{VMON\_STAT\_1 Register} table from when error is detected to when voltage monitor < main band gap .... 100
- Changed \textit{set to 1} text of \textit{D[0]} in the \textit{VMON\_STAT\_1 Register} table from when error is detected to when voltage monitor > main band gap .... 100
- Changed \textit{m} when error is detected to when voltage monitor > main band gap ................................................................. 100
- Changed name of \textit{D6} from VDD3\_ILIM to VDD3\_5\_ILIM in the \textit{SAFETY\_STAT\_1 Register} table ................................ 102
- Added \textit{note to D[7]} description in the \textit{SAFETY\_STAT\_1 Register} table .................................................. 102
- Added \textit{EEPROM} bullet to \textit{D[5]} description in the \textit{SAFETY\_STAT\_2 Register} table .................................................. 103
- Added \textit{DIAGNOSTIC} and \textit{ACTIVE} state text to \textit{D[2:0]} default bullet in the \textit{SAFETY\_STAT\_2 Register} table .... 103
- Added cleared to text to \textit{D[5]} description in the \textit{SAFE STATE\_3 Register} table .................................................. 104
- Changed \textit{D7} and \textit{D6} from 1 to 0 in the \textit{SAFE STATE\_4 Register} table .................................................. 104
- Changed name of \textit{D0} from TRIM\_ERR to TRIM\_ERR\_VMON in the \textit{SAFE STATE\_3 Register} table .................................................. 105
- Added cleared to bullet and note to \textit{D[7:6]} description in the \textit{SAFE STATE\_4 Register} table .................................................. 105
- Changed \textit{set to text} to include error-signal monitoring in the \textit{D[3]} description in the \textit{SAFE STATE\_4 Register} table .................................................................................. 105
- Added \textit{ERROR\_PIN\_FAIL} text to \textit{D[3]} cleared description in the \textit{SAFE STATE\_4 Register} table .................................................. 105
- Added Watchdog Fail Counter text to the \textit{D[2] set to and cleared to} descriptions in the \textit{SAFE STATE\_4 Register} table .................................................................................. 105
- Deleted \textit{SPI read access} from \textit{D[1] cleared to description} in the \textit{SAFE STATE\_4 Register} table .................................................. 105
- Changed \textit{SPI read access} to \textit{NOR} in the \textit{D[0] cleared to description} in the \textit{SAFE STATE\_4 Register} table ........ 105
- Changed \textit{D4} from 1 to 0 and \textit{D1} and \textit{D0} from 0 to 1 in the \textit{SAFE STATE\_5 Register} table .................................................. 106
- Changed \textit{threshold from max to min} for the 0000 setting description in the \textit{SAFE\_ERR\_CFG\_Register} table ........ 106
- Changed \textit{D7} and \textit{D6} from 1 to 0 in the \textit{SAFE\_BIST\_CTRL Register} table .................................................. 107
- Changed \textit{D3 from LOCLK\_EN to RSV in the SAFE\_BIST\_CTRL Register} table .................................................. 107
- Added \textit{ACTIVE} state bullet to \textit{D[7:6]} description in the \textit{SAFE\_BIST\_CTRL Register} table .................................................. 107
- Added \textit{DIAGNOSTIC} and \textit{ACTIVE} states to \textit{D[5]} description in the \textit{SAFE\_BIST\_CTRL Register} table .................................................................................. 107
• Changed D4 from NO_WRST to RSV in the SAFETY_CHECK_CTRL Register table ................................. 108
• Added DEV_CFG2 and DEV_CFG1 to D[7] list of protected registers in the SAFETY_CHECK_CTRL Register table ........................................................................................................... 108
• Added device state, ENDRV and NRES to D[6] description in the SAFETY_CHECK_CTRL Register table ....................................................................................................................... 108
• Changed D[3] from not read/writeable to read/writeable in the SAFETY_CHECK_CTRL Register table ............................................................................................................................. 108
• Added ERROR_PIN_FAIL sub-bullet to D[2] description in the SAFETY_CHECK_CTRL Register table ................................................................................................................................. 108
• Changed D7 from 0 to 1 in the SAFETY_FUNC_CFG Register table...................................................... 109
• Changed D2 from RSV to DIS_NRES_MON in the SAFETY_FUNC_CFG Register table .......................... 109
• Changed D0 from 0 to X in the SAFETY_FUNC_CFG Register table .................................................... 109
• Added new TOKEN seed bullet and sub-bullets to the D[3:0] description in the SAFETY_FUNC_CFG Register table .......................................................................................................................... 109
• Added bullets to the D[7:4] description in the SAFETY_FUNC_CFG Register table .............................. 109
• Changed D2 from 1 to 0 in the SAFETY_FUNC_CFG Register table ..................................................... 109
• Added SDO diagnostics from D[1:0] description to the D[6] description in the SAFETY_FUNC_CFG Register table ...................................................................................................................... 109
• Changed D[7] description from high-impedance to tri-stated in the SAFETY_FUNC_CFG Register table ................................................................................................................................. 109
• Changed D4 from 1 to 0 in the SAFETY_FUNC_CFG Register table ..................................................... 109
• Added _THR to PWD names for D3:D0 in the SAFETY_FUNC_CFG Register table ............................... 109
• Added WD_RST_EN text and SAFE state text to the D[5] set to description in the SAFETY_ERR_STAT Register table ............................................................................................................................. 110
• Added watchdog fail counter text to D[4] cleared to description in the SAFETY_ERR_STAT Register table ................................................................................................................................. 110
• Added equation and oscillator text to the SAFETY_ERR_PWM_H Register table description ............. 110
• Changed D4, D2, and D0 from 0 to 1 in the SAFETY_ERR_PWM_L Register description ...................... 111
• Added equations and oscillator text to the SAFETY_ERR_PWM_H Register table description .......... 111
• Changed D4 from 1 to 0 in the SAFETY_PWDT_THR_CFG Register table ........................................... 111
• Changed _THR to PWD names for D3:D0 in the SAFETY_PWDT_THR_CFG Register table .................. 111
• Changed D7, D5, and D3 from 0 to 1 in the SAFETY_CFG_CRC Register table.................................. 111
• Changed D4 from 0 to 1 in the SAFETY_CFG_CRC Register table ..................................................... 111
• Changed D[7] description from high-impedance to tri-stated in the DIAGCFG_CTRL Register table ................................................................................................................................. 112
• Added SDO diagnostics from D[1:0] description to the D[6] description in the DIAGCFG_CTRL Register table ................................................................................................................................. 112
• Changed D2 from 0 to 1 in the WDT_TOKEN_FDBCK Register table .................................................. 113
• Added new TOKEN seed bullet and sub-bullets to the D[3:0] description in the WDT_TOKEN_FDBCK Register table ............................................................................................................................. 113
• Changed D6:D0 from 0 to 1 in the WDT_WIN1_CFG Register table ..................................................... 113
• Changed D4:D3 from 0 to 1 in the WDT_WIN2_CFG Register table ..................................................... 113
• Changed D7 from 0 to 1 in the WDT_TOKEN_VALUE Register table .................................................. 114
• Changed MCU sub-bullet from D[7] description to replace Q&A sub-bullet in the D[3:0] description of the WDT_TOKEN_VALUE Register table ................................................................. 114
• Changed D7:D6 from 0 to 1 in the WDT_STATUS Register table ....................................................... 114
• Changed D7:D6 from 0 to 1 in the WDT_STATUS Register table ....................................................... 114
• Changed set to text of the D[5] description in the WDT_STATUS Register table ................................. 114
• Changed D[4] note from recommendation to clear bit to remains set to 1 in the SENS_CTRL Register table ................................................................................................................................. 115
• Changed Typical Application Diagram image....................................................................................... 117
## Changes from Original (July 2016) to Revision A

<table>
<thead>
<tr>
<th>Changes</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changed current limit for 6-V pre-regulator from 1.5 A to 1.3 A in the <strong>FEATURES</strong> list</td>
<td>1</td>
</tr>
<tr>
<td>Added current limit to the 5-V (CAN) bullet in the <strong>FEATURES</strong> list</td>
<td>1</td>
</tr>
<tr>
<td>Added current limit to the 3.3-V or 5-V MCU I/O Voltage bullet in the <strong>FEATURES</strong> list</td>
<td>1</td>
</tr>
<tr>
<td>Deleted reverse battery protection bullet from the <strong>FEATURES</strong> list</td>
<td>1</td>
</tr>
<tr>
<td>Changed current limit from 300 mA to 100 mA in the sensor supply bullet in the <strong>FEATURES</strong> list</td>
<td>1</td>
</tr>
<tr>
<td>Deleted wake-up and enable circuit bullets from the <strong>FEATURES</strong> list</td>
<td>1</td>
</tr>
<tr>
<td>Added <strong>Independent</strong> to voltage monitoring bullet in the <strong>FEATURES</strong> list</td>
<td>1</td>
</tr>
<tr>
<td>Added <strong>Independent Bandgap Reference</strong> bullet to the <strong>FEATURES</strong> list</td>
<td>1</td>
</tr>
<tr>
<td>Added <strong>Diagnostic Output Pin</strong> bullet to the <strong>FEATURES</strong> list</td>
<td>1</td>
</tr>
<tr>
<td>Added <strong>Safing-Pin</strong> and <strong>IGNITION Pin</strong> bullets to the <strong>FEATURES</strong> list</td>
<td>1</td>
</tr>
<tr>
<td>Changed document status from <strong>Product Preview to Production Data</strong></td>
<td>1</td>
</tr>
<tr>
<td>Added CAN Transceiver sentence to the second paragraph in the <strong>DESCRIPTION</strong></td>
<td>1</td>
</tr>
<tr>
<td>Changed adjustable core voltage range from 0.8 and 2.6 V to 0.8 and 3.3 V in the <strong>DESCRIPTION</strong></td>
<td>1</td>
</tr>
<tr>
<td>Added diagnostic output pin and enable output to the list of features listed in the eighth paragraph in the <strong>DESCRIPTION</strong></td>
<td>1</td>
</tr>
<tr>
<td>Changed to data manual template to include table of contents and section numbers</td>
<td>2</td>
</tr>
<tr>
<td>Added ADC, VDD6, to <strong>Typical Application Diagram</strong></td>
<td>2</td>
</tr>
<tr>
<td>Changed <strong>PGND</strong> type from input to ground in <strong>PIN FUNCTIONS</strong> table</td>
<td>27</td>
</tr>
<tr>
<td>Changed <strong>POS</strong> numbers in <strong>ABSOLUTE MAXIMUM RATINGS</strong> table for adjustments</td>
<td>29</td>
</tr>
<tr>
<td>Changed <strong>POS</strong> numbers in <strong>ABSOLUTE MAXIMUM RATINGS</strong> table for adjustments</td>
<td>29</td>
</tr>
<tr>
<td>Added Charge-pump overdrive voltage to the <strong>ABSOLUTE MAXIMUM RATINGS</strong> table</td>
<td>29</td>
</tr>
<tr>
<td>Deleted <strong>DMUXO</strong> from Logic I/O voltage list (M1.15) in the <strong>ABSOLUTE MAXIMUM RATINGS</strong> table</td>
<td>29</td>
</tr>
<tr>
<td>Deleted T&lt;sub&gt;j&lt;/sub&gt; min value of –40 from <strong>ABSOLUTE MAXIMUM RATINGS</strong> table</td>
<td>29</td>
</tr>
<tr>
<td>Changed unit for CDM on corner pins (750) from kV to V in the <strong>ABSOLUTE MAXIMUM RATINGS</strong> table</td>
<td>29</td>
</tr>
<tr>
<td>Deleted T&lt;sub&gt;j&lt;/sub&gt; min value of –40 from <strong>ABSOLUTE MAXIMUM RATINGS</strong> table</td>
<td>30</td>
</tr>
<tr>
<td>Deleted VDDIO internal pullup diode note from the <strong>RECOMMENDED OPERATING CONDITIONS</strong> table</td>
<td>30</td>
</tr>
<tr>
<td>Added values to the current consumption parameter in the <strong>RECOMMENDED OPERATING CONDITIONS</strong> table</td>
<td>30</td>
</tr>
<tr>
<td>Changed condition statement for the <strong>ELECTRICAL CHARACTERISTICS</strong> table by adding T&lt;sub&gt;a&lt;/sub&gt; over junction temperature with up to 150°C</td>
<td>30</td>
</tr>
<tr>
<td>Added VDD6&lt;sub&gt;ripple&lt;/sub&gt; parameter to the <strong>ELECTRICAL CHARACTERISTICS</strong> table</td>
<td>32</td>
</tr>
<tr>
<td>Added VDD6 output voltage to I&lt;sub&gt;VDD&lt;/sub&gt; parameter (A1.2) in the <strong>ELECTRICAL CHARACTERISTICS</strong> table</td>
<td>32</td>
</tr>
<tr>
<td>Changed example to V&lt;sub&gt;dropout&lt;/sub&gt; (A1.3) test condition in the <strong>ELECTRICAL CHARACTERISTICS</strong> table</td>
<td>32</td>
</tr>
<tr>
<td>Changed I&lt;sub&gt;VDD6,lim&lt;/sub&gt; parameter description from current-limit to peak current in the <strong>ELECTRICAL CHARACTERISTICS</strong> table</td>
<td>32</td>
</tr>
<tr>
<td>Changed A1.5 from f&lt;sub&gt;SW, VDD6&lt;/sub&gt;, switching frequency to f&lt;sub&gt;clk, VDD6&lt;/sub&gt;, clock frequency, added note, and deleted test condition from the <strong>ELECTRICAL CHARACTERISTICS</strong> table. Also added test condition</td>
<td>32</td>
</tr>
<tr>
<td>Changed test condition for DC&lt;sub&gt;VDD6&lt;/sub&gt; parameter (A1.6) from VBATP &gt; 7 V to 0 &lt; I&lt;sub&gt;VDD6&lt;/sub&gt; &lt; 1.3 A in the <strong>ELECTRICAL CHARACTERISTICS</strong> table</td>
<td>32</td>
</tr>
<tr>
<td>Added Hysteresis parameter, min and max values to Tprot&lt;sub&gt;VDD6&lt;/sub&gt; (A1.7) in the <strong>ELECTRICAL CHARACTERISTICS</strong> table. Changed test condition from Global shutdown to Protection of VDD6, shared with VDD3/5 thermal protection. for both Tprot&lt;sub&gt;VDD6&lt;/sub&gt; parameters</td>
<td>32</td>
</tr>
<tr>
<td>Added Hysteresis parameter, min and max values to Tprot&lt;sub&gt;VDD6&lt;/sub&gt; (2.13) in the <strong>ELECTRICAL CHARACTERISTICS</strong> table. Changed test condition from VDD5 switch-off to Protection of VDD5. In case of detected over-temperature, only VDD5 will be switched-off for both Tprot&lt;sub&gt;VDD6&lt;/sub&gt; parameters</td>
<td>32</td>
</tr>
<tr>
<td>Added VDD3/5 end-value to test condition for the dVDD35/dt parameter (3.11) in the <strong>ELECTRICAL CHARACTERISTICS</strong> table</td>
<td>32</td>
</tr>
<tr>
<td>Added Hysteresis parameter, min and max values to Tprot&lt;sub&gt;VDD5&lt;/sub&gt; (3.13) in the <strong>ELECTRICAL CHARACTERISTICS</strong> table. Changed test condition from Global shutdown to Protection of VDD3/5, treated as global thermal shutdown (shutdown for all regulators) for both Tprot&lt;sub&gt;VDD5&lt;/sub&gt; parameters</td>
<td>33</td>
</tr>
<tr>
<td>Added test condition to the dVDD1/dt parameter (A4.14) in the <strong>ELECTRICAL CHARACTERISTICS</strong> table</td>
<td>34</td>
</tr>
<tr>
<td>Added VSOUT1 text to test condition for VSOUT1 parameter (5.1) in the <strong>ELECTRICAL CHARACTERISTICS</strong> table</td>
<td>34</td>
</tr>
<tr>
<td>Changed MVVSOUT1 min and max values from –15 and 15 to –35 and 35 in the <strong>ELECTRICAL CHARACTERISTICS</strong> table</td>
<td>34</td>
</tr>
<tr>
<td>Added min and max values for the Threshold for tracking/non-tracking parameter in the <strong>ELECTRICAL CHARACTERISTICS</strong> table</td>
<td>34</td>
</tr>
</tbody>
</table>
| Added Hysteresis parameter, min and max values to Tprot<sub>VSOUT1</sub> (5.13) in the **ELECTRICAL CHARACTERISTICS** table. Changed test condition from VSOUT1 switch-off to Protection of Sensor Supply.
Only VSOUT1 switch-off for both Tprot/VSOUT1 parameters ......................................................... 34

- Changed min and max values for VBATP_OVhys parameter from 29.5 and 32.5 to 34.7 and 36.7 (respectively) in the ELECTRICAL CHARACTERISTICS table. Also added test condition ................................................................................. 34
- Deleted VBATP_OVhys (Pos 6.6) from the ELECTRICAL CHARACTERISTICS table .......................................................... 34
- Changed min and max values for VBATP_OVhys parameter from 29 and 32 to 34.4 and 36.3 (respectively) in the ELECTRICAL CHARACTERISTICS table. Also added test condition ................................................................................. 34
- Added Hysteresis parameter, min and max values to VDD5_UV (6.8) in the ELECTRICAL CHARACTERISTICS table. .................................................................................................................. 34
- Changed max value for VDD5_OV from 5.5 to 5.45 in the ELECTRICAL CHARACTERISTICS table ................................................................................................................................. 34
- Added Hysteresis parameter, min and max values to VDD5_OV (6.10) in the ELECTRICAL CHARACTERISTICS table. .................................................................................................................. 34
- Changed min value for VDD3/5_UV with test condition of 3.3-V setting (undervoltage) from 2.97 to 3 in the ELECTRICAL CHARACTERISTICS table ......................................................................................... 34
- Changed max value for VDD3/5_UV with test condition of 5-V setting (undervoltage) from 4.8 to 4.85 in the ELECTRICAL CHARACTERISTICS table .............................................................................................. 35
- Added Hysteresis parameter for 3.3 and 5 V settings, min and max values to VDD3/5_UV (6.12) in the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 35
- Changed max value for VDD3/5_OV with test condition of 3.3-V setting from 3.63 to 3.6 in the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 35
- Added Hysteresis parameter for 3.3 and 5 V settings, min and max values to VDD3/5_OV (6.14) in the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 35
- Added Hysteresis parameter, min and max values to VDD1_UV (6.16) in the ELECTRICAL CHARACTERISTICS table. Changed test condition from Sensed on VDD1_SENSE pin to Sensed on VDD1_SENSE pin. Relative thresholds are with respect to nominal 800-mV VDD1SENSE (Pos 4.2) for both VDD1_UV parameters .................................................................................................................................................................................. 35
- Added Hysteresis parameter, min and max values to VDD1_OV (6.17) in the ELECTRICAL CHARACTERISTICS table. Changed test condition from Sensed on VDD1_SENSE pin to Sensed on VDD1_SENSE pin. Relative thresholds are with respect to nominal 800-mV VDD1SENSE (Pos 4.2) for both VDD1_OV parameters .................................................................................................................................................................................. 35
- Added Hysteresis parameter, min and max values to VSOUT1_UV (6.19) in the ELECTRICAL CHARACTERISTICS table. Changed test condition from Sensed on VSFB1 pin to Sensed on VSFB1 pin
  Relative thresholds are: for both VSOUT1_UV parameters .................................................................................................................. 35
- Added Hysteresis parameter, min and max values to VSOUT1_UV (6.20) in the ELECTRICAL CHARACTERISTICS table. Changed test condition from Sensed on VSFB1 pin to Sensed on VSFB1 pin
  Relative thresholds are: for both VSOUT1_UV parameters .................................................................................................................. 35
- Added Hysteresis parameter, min and max values to VDD6_UV (6.22) in the ELECTRICAL CHARACTERISTICS table. Also added test condition for both VDD6_UV parameters .................................................................................................................. 35
- Added Hysteresis parameter, min and max values to VDD6_OV (6.23) in the ELECTRICAL CHARACTERISTICS table. Also added test condition for both VDD6_OV parameters .................................................................................................................. 35
- Added test condition to the I_IGN parameter in the the ELECTRICAL CHARACTERISTICS table (7.4). .......................................................... 35
- Changed I_CAN parameter (7.7) to I_CANWU and added test condition to the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 35
- Changed I_CAN_rev (7.8) max value from 1 to −1 in the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 35
- Added test condition for I_CP (8.2) in the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 35
- Added min and max values for fOSC (8.3) in the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 35
- Deleted min value of 11 for the R_mosm_ENDRV_NRES (9.2a) parameter in the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 36
- Added input and logic 1 to the VENDRV_NRES_TH parameter (9.5) description in the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 36
- Deleted max value from 500 to 450 for the VENDRV_NRES_TH (9.5) parameter in the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 36
- Added note reference and test condition to the VDIGIN_LOW Parameter (10.2) in the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 36
- Added note reference and test condition to the VDIGIN_HYST parameter (10.3) in the ELECTRICAL CHARACTERISTICS table. Also added parameter name .................................................................................................................. 36
- Changed 10.4 from empty to the R_DIGOUT_AMUX parameter to the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 36
- Added pin note to the VDIGOUT_HIGH parameter (10.5) in the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 36
- Added pin note to the VDIGOUT_LOW parameter (10.6) in the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 36
- Added min and max values for VELSEXT(0kΩ) (9.4a) in the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 36
- Added RWD_pulse parameter to the ELECTRICAL CHARACTERISTICS table .................................................................................................................. 37

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Product Folder Links: TPS65381-Q1
• Added for MCU error signal monitor to the \( t_{\text{ERROR, WDI, debog}} \) parameter (12.1) in the ELECTRICAL CHARACTERISTICS table .................................................... 37
• Changed max value for the \( t_{\text{ERROR, WDI, debog}} \) parameter (12.1) from 15.75 to 16.25 in the ELECTRICAL CHARACTERISTICS table.......................................................... 37
• Added two test conditions to the \( f_{\text{SPI}} \) parameter (13.1) and removed the single max value of 8 to replace it with the max value for each condition in the ELECTRICAL CHARACTERISTICS table......................... 37
• Added two test conditions to the \( t_{\text{SPI}} \) parameter (13.2) and removed the single min value of 125 to replace it with the min value for each condition in the ELECTRICAL CHARACTERISTICS table............................ 37
• Changed max value for \( t_{\text{max}} \) (13.7) to min value in the ELECTRICAL CHARACTERISTICS table. Also changed parameter description from rising edge to falling edge of SCLK......................................................... 37
• Changed min value from 250 to 788 for the \( t_{\text{hilo}} \) parameter (13.10) in the ELECTRICAL CHARACTERISTICS table. Also added NCS high text to parameter description ......................................................... 37
• Added test condition to the \( f_{\text{clock}} \) parameter (11.1) in the ELECTRICAL CHARACTERISTICS table.......................................................... 37
• Added SDO transition from tri-state to \( t_{\text{off}} \) parameter (13.6) description in the ELECTRICAL CHARACTERISTICS table.......................................................... 37
• Changed max value of \( t_{\text{on}} \) from 30 to 53.3 in the ELECTRICAL CHARACTERISTICS table .................................................... 37
• Changed max value of \( t_{\text{off}} \) from 30 to 85.7 in the ELECTRICAL CHARACTERISTICS table. parameter description from falling edge to rising edge of SCLK.......................................................... 37
• Changed \( t_{\text{on}} \) parameter (13.11) description from Hi-Z state to tristate in the ELECTRICAL CHARACTERISTICS table .................................................... 37
• Changed max value of \( t_{\text{on}} \) (13.11) from 15 to 25 in the ELECTRICAL CHARACTERISTICS table .................................................... 37
• Added \( t_{\text{off}} \) to right side of SPI Timing Parameters diagram .................................................... 37
• Added the SPI SDO Buffer Source/Sink Current graph after the ELECTRICAL CHARACTERISTICS table.......................................................... 38
• Changed block diagram .................................................... 39
• Added condition for when the N-channel MOSFET turns on to the second paragraph in the VDD6 Buck Switch Mode Power Supply section .................................................... 40
• Deleted clearing out of SAFETY_STAT from re-enable VDD5 paragrah and changed SENS_CTRL bit from 4 to D4 in the VDD5 Linear Regulator section .................................................... 40
• Added the default VDD1 paragrah to the end of the VDD1 Linear Regulator section .................................................... 42
• Added sentence to the first paragraph in the VSOUT1 Linear Regulator section describing what occurs after completion of the VDDx ramp-up .................................................... 42
• Changed tracking offset from \( \pm 15 \) to \( \pm 35 \) in the VSOUT1 Linear Regulator section .................................................... 42
• Added SPI command setting to the seventh paragraph in the VSOUT1 Linear Regulator section .................................................... 42
• Added DIAGNOSTIC state text to the Wake-Up section .................................................... 43
• Changed second paragraph in the Wake-Up section: changed edge-sensitive to level-sensitive and pulse duration to deglitch time .................................................... 43
• Added during a power-up event to the Reset Extension section and removed VDD1 from the description .................................................... 44
• Deleted open-connect and RESET state sentence from the last paragraph in the Reset Extension section .................................................... 44
• Changed Power-Up and Power-Down Behavior image in the Power-Up and Power-Down Behavior section .................................................... 45
• Added notes to the IGN Power Latch and POST-RUN Reset image in the Power-Up and Power-Down Behavior section .................................................... 46
• Deleted reset driver from ENDRV bullet in the Safety Functions and Diagnostics Overview section .................................................... 47
• Added the Voltage Monitoring Overview table and table reference to the Voltage Monitor (VMON) section .................................................... 47
• Added the Internal Error Signals table .................................................... 49
• Deleted loss-of-power note and cleared-latched bullet from the clock failure list in the Loss-of-Clock Monitor (LCMON) section .................................................... 51
• Added SPI register bit to the latched bullet in the clock failure list in the Loss-of-Clock Monitor (LCMON) section .................................................... 51
• Added ABIST case paragraphs following the Analog BIST Run States image .................................................... 52
• Moved Logic Built-In Self-Test (LBIST) section from after DMUX tables and added initialized registers list .................................................... 53
• Deleted VDD5 and VSOUT1 supplies from first paragraph of the Junction Temperature Monitoring and Current Limiting section .................................................... 54
• Added VSD5 and VSOUT1 supplies paragraph to the Junction Temperature Monitoring and Current Limiting section .................................................... 54
• Added .................................................... 54
• Deleted STANDBY State text from the Junction Temperature Monitoring and Current Limiting section and changed to regulated supplies. Also added ENDRV pin .................................................... 54
• Changed third paragraph of the Junction Temperature Monitoring and Current Limiting section to include NRES asserted low and VDD5 reenable .................................................... 54
• Added Thermal and Overcurrent Protect Overview table and table reference to the Junction Temperature Monitoring and Current Limiting section .................................................... 55
• Added analog and digital signals and notes to the Diagnostic Output Pin DIAG_OUT image in the Diagnostic Overview section .................................................... 55
Output Pin DIAG_OUT section .......................................................... 56
• Added added disabled state description for the DIAG_OUT pin in the last paragraph of the Diagnostic Output Pin DIAG_OUT section .......................................................... 56
• Added accuracy and corresponding table note to the voltage range column in the Analog MUX Selection table .... 57
• Added ± percentage to the divide ratio values (except for MAIN_BG and VMON_BG) the Analog MUX Selection table .......................................................... 57
• Changed the DIAG_MUX_SEL column and header in the Analog MUX Selection table .......................................................... 57
• Added the max output resistance column to the Analog MUX Selection table .......................................................... 57
• Changed VSFB1 divide ratio from 1 to 4 in the Analog MUX Selection Table .......................................................... 57
• Added the voltage/signal name for signal number A.7 from BG1 to MAIN_BG in the Analog MUX Selection table .......................................................... 57
• Added additional text and note to further explain the Analog MUX Selection Table .......................................................... 57
• Added second paragraph to the Digital MUX (DMUX) section .......................................................... 57
• Added diagnostic check text, Diagnostic MUX Output state (by MUX_OUT bit), and MUX interconnect check section after DMUX tables .......................................................... 60
• Changed the Watchdog Enable Function image in the WDT Fail Counter, WDT Status, and WDT Fail Event section .................................................................................................................. 61
• Added watchdog fail counter text after the Watchdog Status for Fail Counter Value Range table .......................................................... 61
• Changed trigger events paragraph (third) in the Watchdog Configuration with External Trigger Input (Default Mode) section .................................................................................................................. 63
• Added SPI register names and DIAGNOSTIC state to the open and close window programming sentence in the Watchdog Configuration with External Trigger Input (Default Mode) section .......................................................... 64
• Added the WDTI window sequencing and SPI SW_LOCK paragraphs in the Watchdog Configuration with External Trigger Input (Default Mode) section .......................................................... 64
• Added the WDTI rising edge paragraph in the Watchdog Configuration with External Trigger Input (Default Mode) section and added \( t_{\text{WD\_pulse}} \) filter time paragraph .................................................................................................................. 64
• Added image to the Watchdog Configuration with External Trigger Input (Default Mode) section .......................................................... 65
• Added image to the Watchdog Configuration with External Trigger Input (Default Mode) section .......................................................... 66
• Deleted ASIC reference in the first paragraph of the Watchdog Question /and Answer Configuration Through SPI section .................................................................................................................. 67
• Added starts a new watchdog token-response sequence run to the no-response event description in paragraph four of the Watchdog Question /and Answer Configuration Through SPI section .................................................................................................................. 67
• Added 4-bit word bullet to the Watchdog Token Request definition list in the Watchdog-Related SPI Event Definitions section .................................................................................................................. 67
• Added 32-bit word bullet to the Watchdog Token Timer Request definition list in the Watchdog-Related SPI Event Definitions section .................................................................................................................. 68
• Added Watchdog Token-Response Sequence Run section to replace the Watchdog Timer Configuration for Question and Answer Configuration section .................................................................................................................. 68
• Changed the WDT Token and Response Sequence Run image in the Watchdog Token-Response Sequence Run section .................................................................................................................. 69
• Added the 4-bit question paragraph to the Watchdog Token Value Generation (or Watchdog Question Generation) section .................................................................................................................. 69
• Added the Watchdog TOKEN Generation image and following text in the Watchdog Timer Configuration for Question and Answer Configuration section .................................................................................................................. 70
• Added Answer Comparison and Reference Answer section .................................................................................................................. 72
• Changed WDT answer column header names - switched response 0 and response 3, switched response 2 and response 1 in the Set of 4-Bit WD Token Values and Corresponding 8-Bit Responses table. Added token registerDevice Configuration Register Protection name and value to token column. .................................................................................................................. 73
• Added Watchdog Token-Response Sequence Run and WDT_STATUS Register Updates section .................................................................................................................. 73
• Added activation and deactivation paragraph in the MCU Error Signal Monitor (MCU ESM) section .................................................................................................................. 75
• Added DIAGNOSTIC and ACTIVE state paragraph in the MCU Error Signal Monitor (MCU ESM) section .................................................................................................................. 76
• Added deglitched and synchronized paragraph in the MCU Error Signal Monitor (MCU ESM) section .................................................................................................................. 76
• Added ERROR/WDI pin implementation text in the MCU Error Signal Monitor (MCU ESM) section .................................................................................................................. 76
• Added the first paragraph in the PWM Mode section and added the detect and no detect statements .................................................................................................................. 78
• Added monitoring lists to the PWM Mode section .................................................................................................................. 78
• Changed register setting text for the ERROR_PIN_FAIL bit from error-pin signaling failure to system clock detection to the PWM Mode section .................................................................................................................. 80
• Added CFG_CRC_ERR flag text to the Device Configuration Register Protection section .................................................................................................................. 81
• Changed CRC-8 polynomial from \( X^8 + X^7 + X^6 + X^4 + X^2 + 1 \) to \( X^8 + X^2 + X^1 + 1 \) in the Device Configuration Register Protection section .................................................................................................................. 81
• Added 64-bit string text and protected registers list in the Device Configuration Register Protection section .................................................................................................................. 81
Not Recommended for New Designs

Revision History

• Added CRC Bus Structure table in the Device Configuration Register Protection section ........................................ 82
• Added CRC calculation text, image, and table in the Device Configuration Register Protection section ................ 82
• Added EEPROM CRC check and list of steps in the Device Configuration Register Protection section .............. 82
• Changed the Reset and Enable Circuit image in the Enable and Reset Driver Circuit section ............................... 84
• Added ENDRV pulled low paragraph to the Enable and Reset Driver Circuit section ........................................ 84
• Changed timing-response diagram description from RESET condition to any VDDx UV or OV condition in the Enable and Reset Driver Circuit section .......................................................... 85
• Added RESET condition image in the Enable and Reset Driver Circuit section and replaced it with the any VDDx UV or OV condition image ........................................................................................................ 85
• Changed Device Controller State Diagram image .................................................................................................... 86
• Added Internal NPOR (power-on reset) bullet item in the STANDBY STATE section ........................................... 86
• Changed IGN and CANWU driven low bullet item to deglitched IGN, IGN_PWRL, and CANWU_L with values in the STANDBY STATE section ....................................................................................... 87
• Added device error count text to the SAFE state bullet in the RESET STATE list .................................................. 87
• Deleted the ACTIVE state bullet in the RESET STATE list ....................................................................................... 87
• Added VDD5 sub-bullet in the RESET STATE list .................................................................................................... 87
• Added watchdog fail counter text to the watchdog reset sub-bullet in the RESET STATE list ................................ 87
• Added ramping up sub-bullet to the first item in the RESET STATE list ............................................................... 88
• Added RESET State transition paragraph to the RESET STATE list ................................................................... 88
• Added NRES pulled up to the Enters RESET state bullet in the DIAGNOSTIC STATE list ............................... 88
• Added VSOUT1, watchdog and ERROR/WDI, watchdog failure counter, and ENDRV pin bullets in the DIAGNOSTIC STATE list ........................................................................................................... 88
• Added DIAG_EXIT_MASK and DIAG_EXIT text to the end of the DIAGNOSTIC STATE list ........................... 88
• Changed two bullets in the ACTIVE STATE list and added three additional bullets ............................................ 89
• Added uncontrolled transition sub-bullet to the enters DIAGNOSTIC state bullet in the SAFE STATE list .......... 90
• Changed ACTIVE state read-back error, stays in Safe state, NRES, and VDDx bullets in the SAFE STATE list .... 90
• Added STATE TRANSITION PRIORITIES section ............................................................................................. 91
• Deleted Enters from RESET, DIAGNOSTIC, or ACTIVE state after ABIST or LBIST failure bullet from the SPI 4-pin list in the SPI Interface section ................................................................. 92
• Changed speed from 10 to 6 Mbit/s in the SPI Interface section ............................................................................ 92
• Added minimum time sentence to paragraph after the SPI Command Transfer Phase table ............................... 92
• Deleted paragraph describing the possibility of mixing two access modes in the SPI Data-Transfer Phase section .. 93
• Added minimum time sentence to paragraph after the SPI Data-Transfer Phase table ........................................ 93
• Added status bit paragraph and note after the Device Status Flag Byte Response table .................................... 93
• Added 8-bit hex column to the SPI Command Table ............................................................................................ 95
• Changed D5 from 0 to 1 in the DEV_REV Register table ....................................................................................... 96
• Changed D0 from 0 to 1 in the DEV_REV Register table ....................................................................................... 96
• Changed D0 from 0 to 1 in the DEV_ID Register table .......................................................................................... 97
• Changed reset value text to D[1] and D[0] descriptions in the DEV_STATE Register table .................................. 97
• Changed D6 from MASK_VDD_OV and 1 to nMASK_VDD_UV_OV and 0 in the DEV_CFG1 Register table ......... 98
• Added ground and no ground to the SEL_VDD3/5 description for both 5 V and 3.3 V in the DEV_CFG1 Register table ........................................................................................................................................ 98
• Added value in RESET State text in the DEV_CFG1 Register table ....................................................................... 98
• Added READ-ONLY the DEV_CFG1 Register table ............................................................................................ 98
• Added after first start-up text to D[6] if VDD1 text in the DEV_CFG1 Register table .................................................. 98
• Switched the names of D5 and D4 in DEV_CFG2 Register table ......................................................................... 99
• Changed EN_VDD3/5_OT description by removing extra text after set to 1 and adding two more bullets in the DEV_CFG2 Register table ........................................................................................................ 99
• Changed read/write text for D[3:0] in the DEV_CFG2 Register table ....................................................................... 99
• Changed AVDD_VMON_ERR description from error status to power-good status in the VMON_STAT_1 Register table ..................................................................................................................................... 100
• Changed set to 1 text of D[1] in the VMON_STAT_1 Register table from when error is detected to when voltage monitor < main band gap .................................................................................................... 100
• Changed set to 1 text of D[0] in the VMON_STAT_1 Register table from .............................................................. 100
• Changed m when error is detected to when voltage monitor > main band gap .................................................... 100
• Changed name of D6 from VDD3_ILIM to VDD3_5_ILIM in the SAFETY_STAT_1 Register table ................. 102
• Added set to D[7] description in the SAFETY_STAT_1 Register table ................................................................. 102
• Added EEPROM bullet to D[5] description in the SAFETY_STAT_2 Register table ........................................... 103
• Added DIAGNOSTIC and ACTIVE State text to D[2:0] default bullet in the SAFETY_STAT_2 Register table .......... 103
• Added cleared to text to the D[5] description in the SAFETY_STAT_3 Register table ........................................ 104
• Changed D7 and D6 from 1 to 0 in the SAFETY_STAT_4 Register table
• Changed name of D0 from TRIM_ERR to TRIM_ERR_VMON in the SAFETY_STAT_4 Register table
• Added cleared to bullet and note to D[7:6] description in the SAFETY_STAT_4 Register table
• Changed set to text to include error-signal monitoring in the D[3] description in the SAFETY_STAT_4 Register table
• Added ERROR_PIN_FAIL text to D[3] cleared description in the SAFETY_STAT_4 Register table
• Added Watchdog Fail Counter text to the D[2] set to and cleared to descriptions in the SAFETY_STAT_4 Register table
• Deleted SPI read access from D[1] cleared to description in the SAFETY_STAT_4 Register table
• Changed SPI read access to NPOR in the D[0] cleared to description in the SAFETY_STAT_4 Register table
• Changed D4 from 1 to 0 and D1 and D0 from 0 to 1 in the SAFETY_STAT_5 Register table
• Changed threshold from max to min for the 0000 setting description in the SAFETY_ERR_CFG Register table
• Changed D7 and D6 from 1 to 0 in the SAFETY_BIST_CTRL Register table
• Changed D3 from LOCLK_EN to RSV in the SAFETY_BIST_CTRL Register table
• Added ACTIVE state bullet to D[7:6] description in the SAFETY_BIST_CTRL Register table
• Added DIAGNOSTIC and ACTIVE states to D[5] description in the SAFETY_BIST_CTRL Register table
• Changed D4 from NO_WRST to RSV in the SAFETY_CHECK_CTRL Register table
• Added DEV_CFG2 and DEV_CFG1 to D[7] list of protected registers in the SAFETY_CHECK_CTRL Register table
• Added device state, ENDRV and NRES to D[6] description in the SAFETY_CHECK_CTRL Register table
• Changed D[3] from not read/writeable to read/writeable in the SAFETY_CHECK_CTRL Register table
• Added ERROR_PIN_FAIL sub-bullet to D[2] description in the SAFETY_CHECK_CTRL Register table
• Changed D7 from 0 to 1 in the SAFETY_FUNC_CFG Register table
• Changed D2 from RSV to DIS_NRES_MON in the SAFETY_FUNC_CFG Register table
• Changed D7 and D6 from 1 to 0 in the SAFETY_FUNC_CFG Register table
• Changed name of D0 from TRIM_ERR to TRIM_ERR_VMON in the SAFETY_FUNC_CFG Register table
• Added READ-ONLY bullet, RESET STATE sub-bullet, and connected and not-connected text to the D[0] description in the SAFETY_FUNC_CFG Register table
• Added ERROR/WDI and SAFE state text to the D[5] set to description in the SAFETY_ERR_STAT Register table
• Added WD_RST_EN text to D[4] set to description in the SAFETY_ERR_STAT Register table
• Added watchdog fail counter text to D[4] cleared to description in the SAFETY_ERR_STAT Register table
• Added equation and oscillator text to the SAFETY_ERR_PWM_H Register table description
• Added D4, D2, and D0 from 0 to 1 in the SAFETY_ERR_PWM_L Register table description
• Added equations and oscillator text to the SAFETY_ERR_PWM_H Register table description
• Changed D4 from 1 to 0 in the SAFETY_PWR_THR_CFG Register table
• Changed _THR to PWD names for D3:D0 in the SAFETY_PWR_THR_CFG Register table
• Changed D7, D5, and D3 from 1 to 0 in the SAFETY_CFG_CRC Register table
• Changed D4 from 0 to 1 in the SAFETY_CFG_CRC Register table
• Changed D[7] description from high-impedance to tri-stated in the SAFETY_CFG_CRC Register table
• Added SDO diagnostics from D[1:0] description to the D[6] description in the SAFETY_CFG_CRC Register table
• Changed D2 from 1 to 0 in the WDT_TOKEN_FDBCK Register table
• Added bullets to the D[7:4] description in the WDT_TOKEN_FDBCK Register table
• Added new TOKEN seed bullet and sub-bullets to the D[3:0] description in the WDT_TOKEN_FDBCK Register table
• Changed D6:D0 from 0 to 1 in the WDT_WIN1_CFG Register table
• Changed D4:D3 from 0 to 1 in the WDT_WIN2_CFG Register table
• Changed D7 from 0 to 1 in the WDT_TOKEN_VALUE Register table
• Changed MCU sub-bullet from D[7] description to replace Q&A sub-bullet in the D[3:0] description of the WDT_TOKEN_VALUE Register table
• Changed D7:D6 from 0 to 1 in the WDT_STATUS Register table
• Changed D7:DF from RSV to WD_WRONG_CFG in the WDT_STATUS Register table
### Revision History

- Changed *set to* text of the D[5] description in the *WDT_STATUS Register* table ............................................... 114
- Changed D[4] note from recommendation to clear bit to remains set to 1 in the *SENS_CTRL Register* table ........ 115
- Changed *Typical Application Diagram* image................................................................. 117
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.

DAP Package
32-Pin HTSSOP With PowerPAD™
Top View

Pin Functions

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

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

4.1 Absolute Maximum Ratings

Over operating free-air temperature range (unless otherwise noted)(1)(2)

<table>
<thead>
<tr>
<th>POS</th>
<th>Description</th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1.1</td>
<td>Protected-battery voltage</td>
<td>VBATP, VBAT_SAFING, VSIN</td>
<td>–0.3</td>
<td>40</td>
</tr>
<tr>
<td>M1.2</td>
<td>Charge-pump voltage</td>
<td>VCP, CP1(3)</td>
<td>–0.3</td>
<td>lesser of VBATP + 16 or 52</td>
</tr>
<tr>
<td>M1.3</td>
<td>Charge-pump pumping capacitor voltage</td>
<td>CP2</td>
<td>–0.3</td>
<td>40</td>
</tr>
<tr>
<td>M1.3a</td>
<td>Charge-pump overdrive voltage</td>
<td>VCP(3), VBATP</td>
<td>–0.3</td>
<td>16</td>
</tr>
<tr>
<td>M1.4</td>
<td>VDD6 switching-node voltage</td>
<td>SDN6</td>
<td>–0.3</td>
<td>40</td>
</tr>
<tr>
<td>M1.5</td>
<td>VDD6 output voltage</td>
<td>VDD6</td>
<td>–0.3</td>
<td>40</td>
</tr>
<tr>
<td>M1.6</td>
<td>VDD5 output voltage</td>
<td>VDD5</td>
<td>–0.3</td>
<td>7</td>
</tr>
<tr>
<td>M1.7</td>
<td>VDD3/5 output voltage</td>
<td>VDD3/5</td>
<td>–0.3</td>
<td>7</td>
</tr>
<tr>
<td>M1.8</td>
<td>VDD1_G voltage</td>
<td>VDD1_G</td>
<td>–0.3</td>
<td>15</td>
</tr>
<tr>
<td>M1.10</td>
<td>VDD1SENSE voltage</td>
<td>VDD1SENSE</td>
<td>–0.3</td>
<td>7</td>
</tr>
<tr>
<td>M1.11</td>
<td>Sensor supply tracking voltage</td>
<td>VTRACK1</td>
<td>–0.3</td>
<td>40</td>
</tr>
<tr>
<td>M1.12</td>
<td>Sensor supply output and feedback voltage</td>
<td>VSOUT1, VSFB1(4)</td>
<td>–2</td>
<td>18</td>
</tr>
<tr>
<td>M1.14</td>
<td>Analog/digital reference output voltage</td>
<td>DIAG_OUT</td>
<td>–0.3</td>
<td>7</td>
</tr>
<tr>
<td>M1.15</td>
<td>Logic I/O voltage</td>
<td>VDDIO, ERROR/WDI, ENDRV, NRES, NCS, SDI, SDO, SCLK, RSTEXT</td>
<td>–0.3</td>
<td>7</td>
</tr>
<tr>
<td>M1.16</td>
<td>SEL_VDD3/5</td>
<td>–0.3</td>
<td>40</td>
<td>V</td>
</tr>
<tr>
<td>M1.17</td>
<td>IGN wakeup</td>
<td>IGN</td>
<td>–7</td>
<td>40</td>
</tr>
<tr>
<td>M1.18</td>
<td>CAN wakeup</td>
<td>CANWU</td>
<td>–0.3</td>
<td>40</td>
</tr>
<tr>
<td>M1.19</td>
<td>Operating virtual junction temperature, T_J</td>
<td></td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Storage temperature, T_stg</td>
<td></td>
<td>–65</td>
<td>150</td>
</tr>
</tbody>
</table>

(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

<table>
<thead>
<tr>
<th>POS</th>
<th>Description</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1.21</td>
<td>V_{ESD} Electrostatic discharge</td>
<td>Human body model (HBM), per AEC Q100-002(1)</td>
<td>All pins except VSOUT1 (17) and VSFB1 (15)</td>
</tr>
<tr>
<td>M1.20</td>
<td></td>
<td></td>
<td>On sensor supply pins VSOUT1 (17) and VSFB1 (15)</td>
</tr>
<tr>
<td>M1.22</td>
<td></td>
<td>Charged device model (CDM), per AEC Q100-011</td>
<td>Corner pins (1, 16, 17, and 32)</td>
</tr>
<tr>
<td>M1.23</td>
<td></td>
<td></td>
<td>All pins</td>
</tr>
</tbody>
</table>

(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)

<table>
<thead>
<tr>
<th>POS</th>
<th>Description</th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1.20a</td>
<td>Operating ambient temperature, $T_A$</td>
<td>$-40$</td>
<td>$125$</td>
<td>°C</td>
</tr>
<tr>
<td>R1.1</td>
<td>Minimum input supply voltage on VBATP for initial power up (POS 6.2, VBATP_UV&lt;sub&gt;on&lt;/sub&gt;)(1)(2)</td>
<td>$5.8$</td>
<td>$(5)$</td>
<td>V</td>
</tr>
<tr>
<td>R1.2</td>
<td>Input supply voltage on VBATP after initial power up, functional operation during low input supply voltage events, (POS 6.1, VBATP_UV&lt;sub&gt;on&lt;/sub&gt;)(1)(4)</td>
<td>$4.5$</td>
<td>$5.8$</td>
<td>V</td>
</tr>
<tr>
<td>R1.3</td>
<td>Input supply voltage on VBATP after initial power up, functional operation during low input supply voltage events, (POS 6.1, VBATP_UV&lt;sub&gt;on&lt;/sub&gt;)(1)(4)</td>
<td>$3.3$</td>
<td>$5$</td>
<td>V</td>
</tr>
<tr>
<td>R1.4</td>
<td>VDDIO supply-voltage range</td>
<td>$3.3$</td>
<td>$5$</td>
<td>V</td>
</tr>
<tr>
<td>R1.5</td>
<td>Current consumption in standby mode (all regulator outputs disabled)</td>
<td>$75$</td>
<td>$\mu$A</td>
<td></td>
</tr>
</tbody>
</table>

(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.
(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_UV<sub>rise</sub> and VBATP_UV<sub>fall</sub>. TI recommends enabling overvoltage detection on VBATP (default is enabled, MASK_VBATP_UV = 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

<table>
<thead>
<tr>
<th>THERMAL METRIC(1)</th>
<th>TPS65381-Q1 DAP (HTSSOP)</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{THA}$ Junction-to-ambient thermal resistance</td>
<td>26.3</td>
<td>°C/W</td>
</tr>
<tr>
<td>$R_{THC(top)}$ Junction-to-case (top) thermal resistance</td>
<td>14.1</td>
<td>°C/W</td>
</tr>
<tr>
<td>$R_{THB}$ Junction-to-board thermal resistance</td>
<td>6</td>
<td>°C/W</td>
</tr>
<tr>
<td>$\psi_{JT}$ Junction-to-top characterization parameter</td>
<td>0.2</td>
<td>°C/W</td>
</tr>
<tr>
<td>$\psi_{JB}$ Junction-to-board characterization parameter</td>
<td>6.2</td>
<td>°C/W</td>
</tr>
<tr>
<td>$R_{THC(bot)}$ Junction-to-case (bottom) thermal resistance</td>
<td>0.5</td>
<td>°C/W</td>
</tr>
</tbody>
</table>

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

![Diagram showing derating profile for power dissipation based on High-K JEDEC PCB](image-url)

(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 ($T_{A\text{max}}$) is dependent on the maximum-operating junction temperature ($T_{J\text{max}}$), the maximum power dissipation of the device in the application ($P_{D\text{max}}$), and the junction-to-ambient thermal resistance of the part/package in the application ($R_{THA}$), as given by the following equation: $T_{A\text{max}} = T_{J\text{max}} - (R_{THA} \times P_{D\text{max}})$.

(2) Maximum power dissipation is a function of $T_{J\text{max}}$, $R_{THA}$, and $T_{A}$. The maximum-allowable power dissipation at any allowable ambient temperature is $P_{D} = (T_{J\text{max}} - T_{A}) / R_{THA}$.

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

Over operating ambient temperature $T_A = –40°C$ to the maximum-operating junction temperature $T_J = 150°C$, and with $V_{BATP} = V_{BATP \_SAFING}$ in the recommended operating range (see R1.2 in Section 4.3) (unless otherwise noted)

<table>
<thead>
<tr>
<th>POS</th>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDD6-BUCK WITH INTERNAL FET</td>
<td>$V_{DD6}$</td>
<td>Value of output ceramic capacitor</td>
<td>ESR range 100 mΩ to 300 mΩ</td>
<td>22</td>
<td>47</td>
<td>µF</td>
</tr>
<tr>
<td></td>
<td>$L_{DD6}$</td>
<td>Value of inductor</td>
<td></td>
<td>22</td>
<td>33</td>
<td>µH</td>
</tr>
<tr>
<td>1.1</td>
<td>VDD6</td>
<td>VDD6 output voltage</td>
<td>Average DC value excluding ripple and load transients, VBAT &gt; 7 V, $0 &lt; I_{DD6} &lt; 1.3$ A, including dc line and load regulation, temperature drift, and long-term drift where VBAT = VBATP = VBAT _SAFING</td>
<td>5.4</td>
<td>6</td>
<td>6.6</td>
</tr>
<tr>
<td>1.2</td>
<td>$V_{DD6}$</td>
<td>VDD6 output current</td>
<td>Peak-to-peak, ensured by design</td>
<td>VBAT = VBAT _SAFING = 14 V, $L = 33 $µH, $C = 22 $µF</td>
<td>200</td>
<td>mV</td>
</tr>
<tr>
<td>1.3</td>
<td>$V_{DD6 _lkn}$</td>
<td>VDD6 output dropout voltage</td>
<td>1.3 A</td>
<td>1.3</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td>$I_{DD6 _tk}$</td>
<td>Peak current out of SDN6 pin</td>
<td>1.5</td>
<td>2.5</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>$f_{clk _VDD6}$</td>
<td>Clock Frequency</td>
<td>396</td>
<td>440</td>
<td>484</td>
<td>kHz</td>
</tr>
<tr>
<td>1.6</td>
<td>$V_{DD6 _lkn}$</td>
<td>VDD6 output current</td>
<td>0 &lt; $I_{DD6} &lt; 1.3$ A</td>
<td>VDD6 enters dropout mode (100% duty cycle) for VBATP &lt; 7 V</td>
<td>7%</td>
<td>100%</td>
</tr>
<tr>
<td>1.7</td>
<td>Tprot</td>
<td>Temperature protection threshold</td>
<td>175</td>
<td>210</td>
<td>°C</td>
<td></td>
</tr>
</tbody>
</table>

VDD5 – LDO WITH INTERNAL FET

<table>
<thead>
<tr>
<th>POS</th>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$V_{DD5}$</td>
<td>Value of output ceramic capacitor</td>
<td>ESR range 0 mΩ to 100 mΩ</td>
<td>1</td>
<td>5</td>
<td>µF</td>
</tr>
<tr>
<td>2.1</td>
<td>VDD5</td>
<td>VDD5 output voltage</td>
<td>$0 &lt; I_{DD5} &lt; 300$ mA</td>
<td>4.9</td>
<td>5</td>
<td>5.1</td>
</tr>
<tr>
<td>2.2</td>
<td>$V_{DD5}$</td>
<td>VDD5 output current, including load from the internal resistor of 660 Ω (typical)</td>
<td></td>
<td>300</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>VDD5_limit</td>
<td>VDD5 output voltage dynamic</td>
<td>Load step 20% to 80% in 5 µs, with $C_{VDD5} = 5$ µF</td>
<td>4.95</td>
<td>5</td>
<td>5.15</td>
</tr>
<tr>
<td>2.4</td>
<td>VDD5_limit</td>
<td>Maximum VDD5 output voltage during VBATP step from 5.5 V to 13.5 V within 10 µs</td>
<td>$C_{VDD5} = 5$ µF, $I_{DD5} &lt; 300$ mA</td>
<td>5.5</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>$V_{dropout5}$</td>
<td>VDD5 output dropout voltage</td>
<td>$V_{dropout5} = (V_{DD5} – VDD5)$</td>
<td>$I_{DD5} &lt; 300$ mA</td>
<td>0.3</td>
<td>V</td>
</tr>
<tr>
<td>2.6</td>
<td>PSRR_VDD5</td>
<td>Power supply rejection ratio</td>
<td>$50 &lt; f &lt; 20$ kHz, VBAT = 10 V, $U = 4$ Vpp.</td>
<td>$C_{VDD5} = 5$ µF, $0 &lt; I_{DD5} &lt; 300$ mA</td>
<td>&gt; 40</td>
<td>dB</td>
</tr>
<tr>
<td>2.7</td>
<td>$R_{INR_VDD5}$</td>
<td>Line regulation ($I_{VDD5}$ constant)</td>
<td>$0 &lt; I_{DD5} &lt; 300$ mA, $8$ V VBATP &lt; 19 V</td>
<td>−25</td>
<td>25</td>
<td>mV</td>
</tr>
<tr>
<td>2.8</td>
<td>$R_{INR_VDD5}$</td>
<td>Load regulation (VDD5 constant)</td>
<td>$0 &lt; I_{DD5} &lt; 300$ mA, $8$ V VA &lt; 19 V</td>
<td>−25</td>
<td>25</td>
<td>mV</td>
</tr>
<tr>
<td>2.9</td>
<td>Tmp_CO_VDD5</td>
<td>Temperature drift</td>
<td>Normalized to 25°C value</td>
<td>−0.5%</td>
<td>0.5%</td>
<td></td>
</tr>
<tr>
<td>2.11</td>
<td>$I_{VDDS_st}$</td>
<td>dV/dt at VDDS at startup</td>
<td>Between 10% and 90% of VDD5 end-value</td>
<td>5</td>
<td>50</td>
<td>V/ms</td>
</tr>
<tr>
<td>2.13</td>
<td>Tprop_VDD5</td>
<td>Temperature protection threshold</td>
<td>175</td>
<td>210</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>2.14</td>
<td>$I_{VDDS_lkn}$</td>
<td>Current–limit</td>
<td></td>
<td>350</td>
<td>650</td>
<td>mA</td>
</tr>
</tbody>
</table>

(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) $I_{DD6}$ 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 conv enters may be connected directly as along as the total load current on VDD6, $I_{DD6}$ 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 $F_{clk \_VDD6}$ clock. If no switching is needed when the rising edge of the $F_{clk \_VDD6}$ 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 $F_{clk \_VDD6}$ 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 $F_{clk \_VDD6}$ 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) $I_{VDDS\_lkn}$ 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.

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Electrical Characteristics (continued)

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

<table>
<thead>
<tr>
<th>POS</th>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDD3/5 – LDO WITH INTERNAL FET</td>
<td>AN $V_{PDSS}$</td>
<td>Value of output ceramic capacitor</td>
<td>ESR range 0 mΩ to 100 mΩ</td>
<td>1</td>
<td>5</td>
<td>μF</td>
</tr>
<tr>
<td>3.1a</td>
<td>I$_{VDD3/5}$</td>
<td>VDD3/5 output voltage, SEL_VDD3/5 pin: open = 3.3 V setting, ground = 5 V setting</td>
<td>0 &lt; $I_{VDD3/5}$ &lt; 300 mA</td>
<td>3.3-V Setting</td>
<td>3.234</td>
<td>3.3</td>
</tr>
<tr>
<td>3.1b</td>
<td>$V_{DD1_\text{G}}$</td>
<td>VDD1 output voltage, depends on external resistive divider</td>
<td>5-V Setting</td>
<td>4.9</td>
<td>5</td>
<td>5.1</td>
</tr>
<tr>
<td>3.2</td>
<td>$I_{VDD3/5}$</td>
<td>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(11)</td>
<td>300</td>
<td>mA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.3a</td>
<td>$V_{VDD3/5_\text{SM}}$</td>
<td>VDD3/5 output voltage dynamic</td>
<td>Load step 20% to 80% in 5 μs, with $C_{VDD6} = 5$ μF</td>
<td>3.3-V Setting</td>
<td>3.15</td>
<td>3.3</td>
</tr>
<tr>
<td>3.3b</td>
<td>$V_{VDD3/5_\text{SM}}$</td>
<td>VDD3/5 output voltage dynamic</td>
<td>5-V Setting</td>
<td>4.85</td>
<td>5</td>
<td>5.15</td>
</tr>
<tr>
<td>3.4</td>
<td>V$_{VDD3/5_\text{SM}}$</td>
<td>Maximum VDD3/5 output voltage during VBATP step</td>
<td>$C_{VDD6} = 5$ μF, $I_{VDD3/5} &lt; 300$ mA</td>
<td>3.3-V Setting</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>3.5</td>
<td>$V_{VDD3/5_\text{SM}}$</td>
<td>VDD3/5 output dropout voltage</td>
<td>$I_{VDD3/5} &lt; 300$ mA</td>
<td>0.3</td>
<td>0.3</td>
<td>V</td>
</tr>
<tr>
<td>3.6</td>
<td>PSRR$_{VDD3/5}$</td>
<td>Power-supply rejection ratio</td>
<td>$60 &lt; 1 &lt; 20$ kHz, $V_{BATP} = 10$ V, $U = 4$ Vpp, $V_{PDSS} = 5$ μF, $I_{VDD3/5} &lt; 300$ mA</td>
<td>&gt; 40</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>3.7</td>
<td>$V_{I_{R_{PDSS}}}$</td>
<td>Line regulation ($I_{VDD3/5}$ constant)</td>
<td>$0 &lt; I_{VDD3/5} &lt; 300$ mA, 8 V ≤ $V_{BATP}\leq 19$ V</td>
<td>–25</td>
<td>25</td>
<td>mV</td>
</tr>
<tr>
<td>3.8</td>
<td>LdReg$_{VDD3/5}$</td>
<td>Load regulation (VDD6 constant)</td>
<td>$0 &lt; I_{VDD3/5} &lt; 300$ mA, 8 V ≤ $V_{BATP}\leq 19$ V</td>
<td>–25</td>
<td>25</td>
<td>mV</td>
</tr>
<tr>
<td>3.9</td>
<td>$I_{\text{R_{Th}}}$</td>
<td>Temperature drift</td>
<td>Normalized to 25°C value</td>
<td>–0.5%</td>
<td>0.5%</td>
<td></td>
</tr>
<tr>
<td>3.11</td>
<td>dv/dt</td>
<td>dv/dt at VDD3/5 at start-up</td>
<td>Between 10% and 90% of VDD3/5</td>
<td>3.3-V Setting</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>3.12</td>
<td>$T_{prot}$</td>
<td>Temperature protection threshold(12)</td>
<td></td>
<td>5</td>
<td>50</td>
<td>°C</td>
</tr>
<tr>
<td>3.13</td>
<td>$I_{\text{R_{Th}}}$</td>
<td>Current-limit(13)</td>
<td></td>
<td>350</td>
<td>650</td>
<td>mA</td>
</tr>
<tr>
<td>3.14</td>
<td>$I_{\text{R_{Th}}}$</td>
<td>Pulldown current on SEL_VDD3/5 pin</td>
<td></td>
<td>20</td>
<td>μA</td>
<td></td>
</tr>
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</table>

VDD1 – LDO WITH EXTERNAL FET

<table>
<thead>
<tr>
<th>POS</th>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN</td>
<td>$V_{G(s)}$</td>
<td>Gate threshold voltage, external FET</td>
<td>IO = 1 mA</td>
<td>0.3</td>
<td>3</td>
<td>V</td>
</tr>
<tr>
<td>AN</td>
<td>$C_{iss}$</td>
<td>Gate capacitance, external FET</td>
<td>VGS = 0 V</td>
<td>3200</td>
<td>pF</td>
<td></td>
</tr>
<tr>
<td>AN</td>
<td>$Q_{gate}$</td>
<td>Gate Charge, external FET</td>
<td>VGS = 0 to 10 V</td>
<td>70</td>
<td>nC</td>
<td></td>
</tr>
<tr>
<td>AN</td>
<td>$g_{fs}$</td>
<td>Forward transconductance, external FET</td>
<td>IO = 50 mA</td>
<td>0.4</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>AN</td>
<td>$C_{PD1}$</td>
<td>Value of output ceramic capacitor</td>
<td>ESR range 0 mΩ to 100 mΩ</td>
<td>5</td>
<td>40</td>
<td>μF</td>
</tr>
<tr>
<td>4.1</td>
<td>VDD1</td>
<td>VDD1 output voltage, depends on external resistive divider</td>
<td>0.8</td>
<td>3.3</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>VDD1</td>
<td>VDD1 reference voltage(7e)</td>
<td>10 mA &lt; $I_{PD1}$ &lt; 600 mA</td>
<td>0.792</td>
<td>0.8</td>
<td>0.808</td>
</tr>
<tr>
<td>4.2a</td>
<td>VDD1</td>
<td>Bias current of VDD1</td>
<td>$V_{PD1}$</td>
<td>–6.6</td>
<td>–10</td>
<td>μA</td>
</tr>
<tr>
<td>4.3</td>
<td>$I_{PD1}$</td>
<td>VDD1 output current</td>
<td>Minimum current realized with external resistive divider</td>
<td>10</td>
<td>600</td>
<td>mA</td>
</tr>
<tr>
<td>4.4</td>
<td>$I_{PD1_G}$</td>
<td>VDD1_G output voltage</td>
<td>Referenced to GND</td>
<td>15</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>4.5</td>
<td>$I_{PD1_G}$</td>
<td>VDD1_G voltage in OFF condition</td>
<td>20 μA into VDD1_G pin</td>
<td>0.3</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>4.6</td>
<td>$I_{PD1_G}$</td>
<td>DC load current</td>
<td></td>
<td>200</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td>4.7</td>
<td>VDD1</td>
<td>VDD1 output voltage dynamic</td>
<td>Load step 10% to 90% in 1 μs, with $C_{PD1} = 40$ μF(15)</td>
<td>± 4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.8</td>
<td>$V_{PD1_\text{MAX}}$</td>
<td>Maximum VDD1 output voltage during VBATP step</td>
<td>from 5.5 V to 13.5 V within 10 μs</td>
<td>3.3-V Setting</td>
<td>0.898</td>
<td>V</td>
</tr>
<tr>
<td>4.9</td>
<td>PSRR$_{VDD1}$</td>
<td>Power-supply rejection ratio</td>
<td>$50 &lt; 1 &lt; 20$ kHz, $V_{BATP} = 10$ V, $U = 4$ Vpp, $V_{PD1} = 10$ μF, $I_{PD1} &lt; 600$ mA</td>
<td>&gt; 40</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>4.10</td>
<td>LdReg$_{VDD1}$</td>
<td>Line regulation on VDD1 (VDD1 constant)</td>
<td>10 mA &lt; $I_{PD1} &lt; 600$ mA, 8 V ≤ $V_{BATP}\leq 19$ V</td>
<td>–7</td>
<td>7</td>
<td>mV</td>
</tr>
<tr>
<td>4.11</td>
<td>LdReg$_{VDD1}$</td>
<td>Load regulation on VDD1 (VDD6 constant)</td>
<td>10 mA &lt; $I_{PD1} &lt; 600$ mA, 8 V ≤ $V_{BATP}\leq 19$ V</td>
<td>–7</td>
<td>7</td>
<td>mV</td>
</tr>
</tbody>
</table>

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

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

(3) $I_{VDD3/5\_\text{SM}}$ 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.

(4) 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.

(5) VDD1$_{dyn}$ will depend on external FET choice.
Electrical Characteristics (continued)

Over operating ambient temperature $T_a = -40°C$ to the maximum-operating junction temperature $T_J = 150°C$, and with VBAT $\neq$ VBAT_SAFING in the recommended operating range (see R1.2 in Section 4.3) (unless otherwise noted)

<table>
<thead>
<tr>
<th>POS</th>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.12</td>
<td>$T_{mpD(y)Vin}$ Temperature drift</td>
<td>Normalized to 25°C value</td>
<td>-0.5%</td>
<td>0.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.14</td>
<td>$I_{VD1/dt}$ dV/dt at VDD1_SENSE at start-up</td>
<td>Between 10% and 90% of VDD1 end-value</td>
<td>0.8</td>
<td>8</td>
<td>V/m</td>
<td></td>
</tr>
</tbody>
</table>

VOUT1 – LDO WITH PROTECTED INTERNAL FET

<table>
<thead>
<tr>
<th>POS</th>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN</td>
<td>$C_{VSOUT}$ Value of output ceramic capacitor</td>
<td>ESR range 0 mΩ to 100 mΩ</td>
<td>μF</td>
</tr>
<tr>
<td>5.1</td>
<td>$V_{SOUT}$ VOUT1 output voltage, depends on external resistive divider and tracking or non-tracking mode</td>
<td>3.3</td>
<td>9.5</td>
</tr>
<tr>
<td>5.2</td>
<td>$M_{V_{SOUT}}$ For tracking mode: Matching output error $M_{V_{SOUT}} = (V_{TRACK1} – V_{SFB1})/I_{PD}$</td>
<td>0 $&lt; I_{SOUT} &lt; 100$ mA</td>
<td>-35</td>
</tr>
<tr>
<td>5.3</td>
<td>$V_{SFB1}$ For non-tracking mode: VOUT1 reference voltage $V_{SOUT1} &lt; 100$ mA</td>
<td>2.45</td>
<td>2.55</td>
</tr>
<tr>
<td>5.3a</td>
<td>$V_{TRACK1_{th}}$ Threshold for selecting tracking/non-tracking mode $V_{TRACK1_{th}} &gt; V_{TH}$ for tracking mode, $V_{TRACK1_{th}} &lt; V_{TH}$ for non-tracking mode</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>5.3b</td>
<td>$I_{VTRACK1_{pd}}$ Internal pulldown resistance on VTRACK1 pin</td>
<td>100</td>
<td>mA</td>
</tr>
<tr>
<td>5.4</td>
<td>$I_{VSOUT}$ VOUT1 output current, including internal resistor to dissipate minimum curent $V_{SOUT1} &gt; 100$ mA</td>
<td>0.75</td>
<td>V</td>
</tr>
<tr>
<td>5.5</td>
<td>$I_{VSIN}$ VOUT1 dropout voltage $I_{VSIN} = (V_{SFB1} – V_{SOUT1})$</td>
<td>0.75</td>
<td>V</td>
</tr>
<tr>
<td>5.6</td>
<td>$PSRR_{SOUT}$ Power-supply rejection ratio With VTRACK1 = GND, VOUT1 = 4.5 V, $50 &lt; I &lt; 20$ kHz, $V_{SOUT1} = 10$ V, $U = 4$ Vpp, $V_{VSOUT1} = 1$ μF, $0 &lt; I_{SOUT} &lt; 100$ mA</td>
<td>&gt; 40</td>
<td>dB</td>
</tr>
<tr>
<td>5.7</td>
<td>$I_{PVT_{VOUT}}$ Line regulation ($V_{SOUT1}$ Constant) $0 &lt; I_{SOUT} &lt; 100$ mA, $V_{SOUT1} &lt; 100$ mA</td>
<td>-25</td>
<td>25</td>
</tr>
<tr>
<td>5.8</td>
<td>$I_{PVT_{VOUT}}$ Load regulation ($V_{SOUT1}$ Constant) $0 &lt; I_{SOUT} &lt; 100$ mA, $V_{SOUT1} &lt; 100$ mA</td>
<td>-35</td>
<td>35</td>
</tr>
<tr>
<td>5.9</td>
<td>$I_{V_{TH}}$ Temperature drift Normalized to 25°C value</td>
<td>-0.5%</td>
<td>0.5%</td>
</tr>
<tr>
<td>5.11</td>
<td>$V_{SOUT1_{th}}$ Output short circuit voltage range $V_{SOUT1}$ $V_{SFB1}$ configured for regulation $V_{SOUT1} &gt; V_{BATP}$, regulator switched off</td>
<td>20</td>
<td>mA</td>
</tr>
<tr>
<td>5.12</td>
<td>$I_{VSIN}$ Output reverse current $V_{SOUT1}$ configured for regulation $V_{SOUT1} = 14$ V and $VBAT = 0$ V, regulator switched off</td>
<td>20</td>
<td>mA</td>
</tr>
<tr>
<td>5.13</td>
<td>$P_{th_{SOUT1}}$ Temperature protection threshold $P_{th_{SOUT1}}$</td>
<td>175</td>
<td>210</td>
</tr>
<tr>
<td>5.14</td>
<td>$I_{PD_{SOUT1}}$ Current-limit</td>
<td>120</td>
<td>500</td>
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</tbody>
</table>

VOLTAGE MONITORING

<table>
<thead>
<tr>
<th>POS</th>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>$VBATP_{UV_{off}}$ VBATP and VBAT_SAFING level for indication by $VBATP_{UV_{comp}}$</td>
<td>4.2</td>
<td>4.5</td>
</tr>
<tr>
<td>6.2</td>
<td>$VBATP_{UV_{off}}$ VBATP and VBAT_SAFING level for indication by $VBATP_{UV_{comp}}$</td>
<td>5.4</td>
<td>5.8</td>
</tr>
<tr>
<td>6.3</td>
<td>$VBATP_{UV_{on}}$ Undervoltage hysteresis</td>
<td>1.1</td>
<td>1.4</td>
</tr>
<tr>
<td>6.4</td>
<td>$VBATP_{OV_{max}}$ VBATP level for setting $VBATP_{OV}$ flag $V_{BATP} = V_{BATP}$</td>
<td>34.7</td>
<td>36.7</td>
</tr>
<tr>
<td>6.5</td>
<td>$VBATP_{OV_{max}}$ VBATP level for clearing $VBATP_{OV}$ flag $V_{BATP} = V_{BATP}$</td>
<td>34.4</td>
<td>36.3</td>
</tr>
<tr>
<td>6.8</td>
<td>$VDD5_{UV}$ VDD5 undervoltage level $V_{BATP} = V_{BATP}$</td>
<td>4.5</td>
<td>4.85</td>
</tr>
<tr>
<td>6.8a</td>
<td>$I_{Hysteresis_{VDD5}}$ VDD5 Hysteresis $V_{BATP} = V_{BATP}$</td>
<td>140</td>
<td>mV</td>
</tr>
<tr>
<td>6.9</td>
<td>$VDD5_{UV_{off}}$ VDD5 undervoltage headroom (VDD5act – $VDD5_{UV_{act}}$) $V_{BATP} = V_{BATP}$</td>
<td>200</td>
<td>mV</td>
</tr>
<tr>
<td>6.10</td>
<td>$VDD5_{OV}$ VDD5 overvoltage level $V_{BATP} = V_{BATP}$</td>
<td>5.2</td>
<td>5.45</td>
</tr>
<tr>
<td>6.10a</td>
<td>$I_{Hysteresis_{VDD5}}$ VDD5 Hysteresis $V_{BATP} = V_{BATP}$</td>
<td>140</td>
<td>mV</td>
</tr>
<tr>
<td>6.11</td>
<td>$VDD5_{OV_{off}}$ VDD5 overvoltage headroom (VDD5act – $VDD5_{OV_{act}}$) $V_{BATP} = V_{BATP}$</td>
<td>200</td>
<td>mV</td>
</tr>
</tbody>
</table>

(16) Referenced to VTRAC1 input, including long-term and temperature drift.
(17) VOUT1 including line and load regulation, temperature drift and long-term drift.
(18) VOUT1 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 VSSIN instead of VDD6.
(19) VOUT1 is connected to VSB1 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 VOUT1 is equal to the supply to the device (VBATP, VBAT_SAFING, and VSSIN where VSSIN is connected to VBATP as it’s supply instead of VDD6) and VSB1 voltage will follow VOUT1 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 VOUT1 Sensor Supply. Only VOUT1 switch-offs off.
(21) VBATP_UB provides VBATP_UB protection of VBATP where UV will be indicated by the VBATP_UV bit in VMON_STAT_1 register. The VBATP_UV 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)

<table>
<thead>
<tr>
<th>POS</th>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.12</td>
<td>VDD3/5_UV</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>3.3-V setting</td>
<td>3</td>
<td>3.17</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5-V setting</td>
<td>4.5</td>
<td>4.85</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>6.12a</td>
<td>Hysteresis</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>3.3-V setting</td>
<td>100</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>6.13</td>
<td>VDD3/5_UVhead (VDD3/5act – VDD3/5_UVact)</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>3.3-V setting</td>
<td>155</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5-V setting</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>6.14</td>
<td>VDD5_3_OV</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>3.3-V setting</td>
<td>3.43</td>
<td>3.6</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5-V setting</td>
<td>5.2</td>
<td>5.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.14a</td>
<td>Hysteresis</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>3.3-V setting</td>
<td>100</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5-V setting</td>
<td>140</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.15</td>
<td>VDD3/5_UVhead (VDD3/5_UVact – VDD3/5act)</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>3.3-V setting</td>
<td>170</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5-V setting</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.16</td>
<td>VDD1_UV</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>Sensed on VDD1_SENSE pin. Relative thresholds are with respect to nominal 800-mV VDD1SENSE (Pos 4.2)</td>
<td>752</td>
<td>784</td>
<td>mV</td>
</tr>
<tr>
<td>6.16a</td>
<td>Hysteresis</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>Sensed on VDD1_SENSE pin. Relative thresholds are with respect to nominal 800-mV VDD1SENSE (Pos 4.2)</td>
<td>10</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>6.17</td>
<td>VDD1_OV</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>Sensed on VDD1_SENSE pin. Relative thresholds are with respect to nominal 800-mV VDD1SENSE (Pos 4.2)</td>
<td>816</td>
<td>848</td>
<td>mV</td>
</tr>
<tr>
<td>6.17a</td>
<td>Hysteresis</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>Sensed on VDD1_SENSE pin. Relative thresholds are with respect to nominal 800-mV VDD1SENSE (Pos 4.2)</td>
<td>9</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>6.19</td>
<td>VSOUT1_UV</td>
<td>Sensed on VSFB1 pin. Relative thresholds (ratio) are:</td>
<td></td>
<td>0.88</td>
<td>0.94</td>
<td>VSOUT1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• For non-tracking mode, with respect to nominal 2.5-V VSFB1 (Pos 5.3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• For tracking mode, with respect to voltage applied on VTRACK1 pin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• In tracking mode, VSOUT1_UV comparator output is valid for VTRACK1 DC condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.20</td>
<td>VSOUT1_OV</td>
<td>Sensed on VSFB1 pin. Relative thresholds (ratio) are:</td>
<td></td>
<td>1.06</td>
<td>1.12</td>
<td>VSOUT1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• For non-tracking mode, with respect to nominal 2.5-V VSFB1 (Pos 5.3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• For tracking mode, with respect to voltage applied on VTRACK1 pin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• In tracking mode, VSOUT1_OV comparator output is valid for VTRACK1 DC condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.22</td>
<td>VDD6_UV</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>$\text{VBATP} + 15$</td>
<td>5.2</td>
<td>5.4</td>
<td>V</td>
</tr>
<tr>
<td>6.22a</td>
<td>Hysteresis</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>$\text{VBATP} + 15$</td>
<td>115</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>6.23</td>
<td>VDD6_OV</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>$\text{VBATP} + 4$</td>
<td>7.8</td>
<td>8.2</td>
<td>V</td>
</tr>
<tr>
<td>6.23a</td>
<td>Hysteresis</td>
<td>$\text{VBATP} = \text{VBAT_SAFING}$</td>
<td>$\text{VBATP} + 4$</td>
<td></td>
<td>115</td>
<td>mV</td>
</tr>
</tbody>
</table>

**IGNITION AND CAN WAKE-UP**

<table>
<thead>
<tr>
<th>POS</th>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>IGN_WUP</td>
<td>$\text{VBATP} = \text{VBAT_SAFING} + 12$ V</td>
<td>2</td>
<td>3</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>7.2</td>
<td>CAN_WUP</td>
<td>$\text{VBATP} = \text{VBAT_SAFING} + 12$ V</td>
<td>2</td>
<td>3</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>7.3</td>
<td>WUP_hyst</td>
<td>$\text{VBATP} = \text{VBAT_SAFING} + 12$ V</td>
<td>50</td>
<td>200</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>7.4</td>
<td>L IGN</td>
<td>IGN pin at 36 V, $\text{VBATP} = \text{VBAT_SAFING} = 12$ V</td>
<td>50</td>
<td></td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>7.5</td>
<td>L IGN_rev</td>
<td>IGN at –7 V, $\text{VBATP} = \text{VBAT_SAFING} + 12$ V</td>
<td>–1</td>
<td></td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>7.7</td>
<td>C_CANWU</td>
<td>CANWU pin at 36 V, $\text{VBATP} = \text{VBAT_SAFING} = 12$ V</td>
<td>50</td>
<td></td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>7.8</td>
<td>L_CANWU</td>
<td>CANWU at –0.3 V, $\text{VBATP} = \text{VBAT_SAFING} = 12$ V</td>
<td></td>
<td></td>
<td>mA</td>
<td></td>
</tr>
</tbody>
</table>

**CHARGE PUMP**

| AN   | $R_pump$ | Pumping capacitor (between CP1 and CP2) | 10 | nF  |
| AN   | $R_{ext}$ | Storage capacitor (between VCP and VBATP) | 100 | nF  |
| 8.1  | VCP_on | VCP output voltage in on-state | $\text{VBATP} > 5.8$ V | $\text{VBATP} > 4$ V, $\text{VBATP} + 15$ V |
| 8.2  | ICP | External load | Load coming from $R_{ext}$ of Reverse Battery Protection | 100 | µA |

(24) Information in SPI register only
(25) For device wake up, $\text{VBATP}$ and $\text{VBAT\_SAFING}$ 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 $\text{VBATP}$ and $\text{VBAT\_SAFING}$ are ramping.

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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)

<table>
<thead>
<tr>
<th>POS</th>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>NOM</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.3</td>
<td>( \text{I}_{CP} )</td>
<td>Change-pump switching frequency</td>
<td>225</td>
<td>250</td>
<td>275</td>
<td>kHz</td>
</tr>
</tbody>
</table>

**RESET AND ENABLE OUTPUTS**

9.1  \( \text{V}_{\text{NRES\_ENDRV\_L}} \) NRES / ENDRV low-output level With external 2-mA open-drain current 0.2 V

9.2  \( \text{R}_{\text{NRES\_ENDRV\_PULLUP}} \) NRES / ENDRV internal pullup resistance 3 \( \Omega \) T

9.2a \( \text{R}_{\text{DS(on)_NRES\_ENDRV}} \) \( \text{R}_{\text{DS(on)}} \) NRES/ENDRV pulldown transistor 40 \( \Omega \)

9.3  \( \text{R}_{\text{RSTEXT}} \) Value of external reset extension resistor, in case of open-connect, device stays in RESET state(26) 0 \( \text{kHz} \) T

9.5  \( \text{V}_{\text{ENDRV\_NRES\_TH}} \) ENDRV and NRES input readback logic 1 threshold Read-back muxed to DIAG_OUT pin 350 \( \text{kHz} \) T

**DIGITAL INPUT / OUTPUT**

10.1 \( \text{V}_{\text{DIGIN\_HIGH}} \) Digital input, high level for NCS, SDI, SCLK, ERROR/WDI and SEL_VDD3/5 2 V

10.2 \( \text{V}_{\text{DIGIN\_LOW}} \) Digital input, low level for NCS, SDI, SCLK, ERROR/WDI and SEL_VDD3/5 0.8 V

10.3 \( \text{V}_{\text{DIGIN\_HYST}} \) Digital input hysteresis for NCS, SCI, SCLK and ERROR/WDI(27) 0.1 V

10.4 \( \text{R}_{\text{PULL_UP}} \) Output resistance at DIAG_OUT pin in AMUX mode BG1 selected on AMUX, < 200 nA current in or out of DIAG_OUT pin 15 \( \text{kHz} \) T

10.5 \( \text{V}_{\text{DIGOUT\_HIGH}} \) Digital output, high level(28) \( I_{\text{OUT}} = -2 \text{ mA (out of pin)} \) VDDIO – 0.2 V

10.6 \( \text{V}_{\text{DIGOUT\_LOW}} \) Digital output, low level(28) \( I_{\text{OUT}} = 2 \text{ mA (into pin)} \) 0.2 V

**SERIAL PERIPHERAL INTERFACE**

13.12 \( \text{PULL\_UP} \) Internal pullup resistor on NCS input pin 40 \( \text{kHz} \) T

13.13 \( \text{PULL\_DOWN} \) Internal pulldown resistor on SDI and SCLK input pins 40 \( \text{kHz} \) T

(26) The maximum resistance recommend for RSTEXT to ground is 120 \( \text{k}\Omega \).
(27) SEL_VDD3/5 is sampled and latched at device power up hysteresis, \( \text{V}_{\text{DIGIN\_HYST}} \), 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)

<table>
<thead>
<tr>
<th>POS</th>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>NOM</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
</table>
| VDD5 – LDO WITH INTERNAL FET 2.12 \( \text{t}_{\text{delayVDD5}} \) 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 \( \text{t}_{\text{VDD3/5}} \) 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 \( \text{t}_{\text{VDD1}} \) VDD1 voltage stabilization delay Maximum delay after CANWU wakeup for VDD1 output to settle 5 ms

**VOLTAGE MONITORING**

6.7 \( \text{t}_{\text{VBATP\_deg}} \) VBATP undervoltage and overvoltage monitor deglitch time 180 \( \mu \text{s} \)

6.18 \( \text{t}_{\text{VDOx\_deg}} \) VDOx undervoltage and overvoltage monitor deglitch time 10 \( \mu \text{s} \)

6.21 \( \text{t}_{\text{VSOUT1\_deg}} \) VSOUT1 undervoltage and overvoltage monitor deglitch time 10 \( \mu \text{s} \)

**IGNITION AND CAN WAKE-UP (IGN AND CANWU)**

7.6 \( \text{t}_{\text{IGN\_deg}} \) IGN deglitch filter time 7.5 \( \mu \text{s} \)

7.9 \( \text{t}_{\text{CANWU\_deg}} \) CANWU deglitch filter time 100 \( \mu \text{s} \)

**RESET AND ENABLE OUTPUTS**

9.4 \( \text{t}_{\text{RSTEXT\_deg}} \) Reset extension delay 22 \( \text{kHz} \)

9.4a \( \text{t}_{\text{RSTTEXT\_deg}} \) Reset extension delay 4.05 \( \text{kHz} \)

(1) 240 \( \mu \text{s} \) for \( \text{VBAT-UV} \) deglitch and 260 \( \mu \text{s} \) for \( \text{VBAT-OV} \) deglitch
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 $VBATP = VBAT\_SAFEING$ in the recommended operating range (see R1.2 in the Section 4.3) (unless otherwise noted)

<table>
<thead>
<tr>
<th>WINDOWS WATCHDOG</th>
<th>POS</th>
<th>$t_{\text{WD_pulse}}$</th>
<th>Deglitch time on ERROR/WDI pin for watchdog-trigger input signal</th>
<th>MIN</th>
<th>NOM</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12.2</td>
<td></td>
<td></td>
<td>14.25</td>
<td>30</td>
<td>32</td>
<td>$\mu$s</td>
</tr>
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**SERIAL PERIPHERAL INTERFACE TIMING**

<table>
<thead>
<tr>
<th>SERIAL PERIPHERAL INTERFACE TIMING</th>
<th>POS</th>
<th>$f_{\text{SPI}}$</th>
<th>SPI clock (SCLK) frequency</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>NOM</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>13.1</td>
<td></td>
<td>VDDIO = 3.3 V</td>
<td>5$^{(2)}$ MHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td></td>
<td></td>
<td>VDDIO = 5 V</td>
<td>6 MHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3)</td>
<td>13.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.3</td>
<td>$t_{\text{high}}$</td>
<td>High time: SCLK logic high duration</td>
<td>VDDIO = 3.3 V</td>
<td>85.7</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>VDDIO = 5 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>13.4</td>
<td></td>
<td>Low time: SCLK logic low duration</td>
<td>VDDIO = 3.3 V</td>
<td>45</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>VDDIO = 5 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.5</td>
<td>$t_{\text{setup}}$</td>
<td>Setup time NCS: time between falling edge of NCS and rising edge of SCLK</td>
<td>VDDIO = 3.3 V</td>
<td>45</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>VDDIO = 5 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>13.7</td>
<td>$t_{\text{hcs}}$</td>
<td>Setup time at SDI: setup time of SDI before the falling edge of SCLK</td>
<td>VDDIO = 3.3 V</td>
<td>15</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>VDDIO = 5 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>13.9</td>
<td>$t_{\text{hlcs}}$</td>
<td>Hold time: time between the falling edge of SCLK and rising edge of NCS</td>
<td>VDDIO = 3.3 V</td>
<td>45</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>VDDIO = 5 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>13.10</td>
<td>$t_{\text{hcs}}$</td>
<td>SPI transfer inactive time (time between two transfers) during which NCS must remain high</td>
<td>VDDIO = 3.3 V</td>
<td>788</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>VDDIO = 5 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(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 $C_{\text{SDO}} = 100$ $\mu$F

(4) MAX SPI Clock tolerance is ±10%

### 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 $VBATP = VBAT\_SAFEING$ in the recommended operating range (see R1.2 in Section 4.3) (unless otherwise noted)

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

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

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Specifications

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4.8 Typical Characteristics

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

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
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_{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_{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_{VDD6}. A general guideline to achieve balanced operation is \( R_{ESR} = L / (15 \times C_{Effective}) \). 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 ±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 ±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 TPS65381-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 ±2% reference (VDD1_SENSE). 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 kΩ to 1 MΩ 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 ±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_SH. 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-overtemperature 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_{pump}) and one storage capacitor (C_{store}). To have sufficient overdrive voltage output 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 TPS65381-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 TPS65381-Q1 device provides a power-latch function (POST_RUN) for this IGN pin, allowing the MCU to decide when to power down the TPS65381-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 TPS65381-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 TPS65381-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 TPS65381-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-kΩ 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.

5.3.8 Reset Extension
During a power-up event, the TPS65381-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-kΩ 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.

1. 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.

2. 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.

3. 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
ign going low ignored because IGN_PWRL bit is set

Device State

IGN_PWRL

MCU sets IGN_PWRL bit
Note: MCU can set this bit only when the device is in DIAGNOSTIC state

POST_RUN_RST

POST_RUN_RST bit cleared when all internal biasing turned off

IGN_PWRL bit is located in SAFETY_FUNC_CFG SPI register
POST_RUN_RST bit is located in DEV_CFG2 SPI register

7.5-ms (min) to 22-ms (max) deglitch time

IGN going low ignored because IGN_PWRL bit is set

IGN_PWRL

MCU clears IGN_PWRL bit

POST_RUN_RST

POST_RUN_RST bit cleared when all internal biasing turned off

Device State

IGN_PWRL

MCU sets IGN_PWRL bit
Note: MCU can set this bit only when the device is in DIAGNOSTIC state

POST_RUN_RST

POST_RUN_RST bit cleared when all internal biasing turned off

IGN going low ignored because IGN_PWRL bit is set

IGN_PWRL

MCU clears IGN_PWRL bit

POST_RUN_RST

POST_RUN_RST bit cleared when all internal biasing turned off

Device State

IGN_PWRL

MCU sets IGN_PWRL bit
Note: MCU can set this bit only when the device is in DIAGNOSTIC state

POST_RUN_RST

POST_RUN_RST bit cleared when all internal biasing turned off

IGN going low ignored because IGN_PWRL bit is set

IGN_PWRL

MCU clears IGN_PWRL bit

POST_RUN_RST

POST_RUN_RST bit cleared when all internal biasing turned off

Device State

IGN_PWRL

MCU sets IGN_PWRL bit
Note: MCU can set this bit only when the device is in DIAGNOSTIC state

POST_RUN_RST

POST_RUN_RST bit cleared when all internal biasing turned off

VDD5/3/1

5 V

3.3 V

1.2 V

(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 TPS65381-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

<table>
<thead>
<tr>
<th>VOLTAGE RAIL</th>
<th>OUTPUT VOLTAGE</th>
<th>CREATED FROM REFERENCE</th>
<th>MONITORING DETECTION THRESHOLDS</th>
<th>MONITORED AGAINST REFERENCE</th>
<th>MONITORED PIN</th>
<th>OV PROTECTION LEVEL</th>
<th>OV PROTECTION REFERENCE</th>
<th>IMPACT ON DEVICE BEHAVIOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUPPLY INPUT</td>
<td></td>
<td></td>
<td>UV</td>
<td>OV</td>
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<tr>
<td>VBAT</td>
<td>N/A</td>
<td>N/A</td>
<td>4.2 to 4.5 V</td>
<td>34.7 to 36.7 V</td>
<td>VMON_BG</td>
<td>VBATP</td>
<td>N/A</td>
<td>N/A</td>
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<td>SUPPLY OUTPUTS</td>
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<td>VDD6</td>
<td>6 V ± 10%</td>
<td>MAIN_BG</td>
<td>5.2 to 5.4 V</td>
<td>7.8 to 8.2 V</td>
<td>VMON_BG</td>
<td>VDD6</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>VDD5</td>
<td>5 V ± 2%</td>
<td>MAIN_BG</td>
<td>4.5 to 4.85 V</td>
<td>5.2 to 5.45 V</td>
<td>VMON_BG</td>
<td>VDD5</td>
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<td>N/A</td>
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<td>VDD3/5 (5 V)</td>
<td>5 V ± 2%</td>
<td>MAIN_BG</td>
<td>4.5 to 4.85 V</td>
<td>5.2 to 5.5 V</td>
<td>VMON_BG</td>
<td>VDD3/5</td>
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<td>N/A</td>
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<td>VDD3/5 (3.3 V)</td>
<td>3.3 V ± 2%</td>
<td>MAIN_BG</td>
<td>3 to 3.17 V</td>
<td>3.43 to 3.6 V</td>
<td>VMON_BG</td>
<td>VDD3/5</td>
<td>N/A</td>
<td>N/A</td>
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<td>VDD1</td>
<td>0.8 V to 3.3 V – 1% to +2%</td>
<td>VDD1</td>
<td>0.94 to 0.98 x VDD1</td>
<td>1.03 to 1.06 x VDD1</td>
<td>VMON_BG</td>
<td>VDD1SENSE</td>
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<td>N/A</td>
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<td>VSCOUT1 (non-tracking)</td>
<td>3.3 V to 9.5 V ± 2%</td>
<td>VDD1</td>
<td>VDD1 SENSE</td>
<td>N/A</td>
<td>VSCFB1</td>
<td>N/A</td>
<td>N/A</td>
<td>SAFETY_STAT1 D5</td>
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<tr>
<td>VSCOUT1 (tracking)</td>
<td>3.3 V to 9.5 V ± 2%</td>
<td>VDD1</td>
<td>VDD1 SENSE</td>
<td>N/A</td>
<td>VSCFB1</td>
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<td>SAFETY_STAT1 D5</td>
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<td>VCP17</td>
<td>17 V (typ)</td>
<td>MAIN_BG</td>
<td>27 V (typ)</td>
<td>VMON_BG</td>
<td>N/A</td>
<td>27 V (typ)</td>
<td>VMON_BG</td>
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<td>VCP12</td>
<td>12 V (typ)</td>
<td>MAIN_BG</td>
<td>7.43 V (typ)</td>
<td>14.2 V (typ)</td>
<td>VMON_BG</td>
<td>14.2 V (typ)</td>
<td>VMON_BG</td>
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<td>AVDD</td>
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<td>Internal LV Zener</td>
<td>3.6 V (typ)</td>
<td>N/A</td>
<td>Independent local band gap</td>
<td>N/A</td>
<td>NA</td>
<td>Internal MV Zener</td>
</tr>
<tr>
<td>AVDD_VMON</td>
<td>6.9 V (typ)</td>
<td>Internal LV Zener</td>
<td>3.56 V (typ)</td>
<td>N/A</td>
<td>Independent local band gap</td>
<td>Indirectly monitoring VBAT_SAFING &lt; 10.48 V</td>
<td>Internal MV Zener</td>
<td>SPI flag VMON_STAT_1 D2; STANDBY state; NRES = 0, ENDRV = 0</td>
</tr>
<tr>
<td>DVDD</td>
<td>3 V (typ)</td>
<td>MAIN_BG</td>
<td>2.472 V (typ)</td>
<td>3.501 V (typ)</td>
<td>VMON_BG</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>INTERNAL REFERENCES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAIN_BG</td>
<td>2.5 V ± 2%</td>
<td>MAIN_BG</td>
<td>2.545 V (typ)</td>
<td>2.567 V (typ)</td>
<td>VMON_BG</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>VMON_BG</td>
<td>2.5 V ± 2%</td>
<td>VMON_BG</td>
<td>2.545 V (typ)</td>
<td>2.567 V (typ)</td>
<td>MAIN_BG</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

(1) N/A = Not applicable
### 5.4.4 TPS65381-Q1 Internal Error Signals

Table 5-2 lists a useful overview of the TPS65381-Q1 device internal error signals and the impact of the signals on the device behavior.

<table>
<thead>
<tr>
<th>DMUX POS. NO.</th>
<th>SIGNAL NAME</th>
<th>DESCRIPTION</th>
<th>DETECTIVE CONDITION (THRESHOLD LEVEL)</th>
<th>DEGLITCH TIME TO SET FLAG (µs)</th>
<th>DEVICE STATE WHEN FLAG IS SET</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1.2</td>
<td>NAVDD_UV</td>
<td>AVDD undervoltage comparator output (inverted)</td>
<td>3.6 V</td>
<td>15 30</td>
<td>LOW LOW STANDBY</td>
</tr>
<tr>
<td>D1.3</td>
<td>BG_ERR1</td>
<td>VMON or main band gap is OFF (set to 1 when VMON band gap &gt; main band gap)</td>
<td>Main band gap = 2.364 (VMON band gap = 2.477) V</td>
<td>15 30</td>
<td>LOW LOW STANDBY</td>
</tr>
<tr>
<td>D1.4</td>
<td>BG_ERR2</td>
<td>VMON or main band gap is OFF (set to 1 when VMON band gap &lt; main band gap)</td>
<td>Main band gap = 2.617 (VMON band gap = 2.477) V</td>
<td>15 30</td>
<td>LOW LOW STANDBY</td>
</tr>
<tr>
<td>D1.5</td>
<td>VCP12_UV</td>
<td>VCP12 charge pump undervoltage comparator (inverted)</td>
<td>7.43 V</td>
<td>15 30</td>
<td>Not changed Not changed Not changed</td>
</tr>
<tr>
<td>D1.6</td>
<td>VCP12_OV</td>
<td>VCP12 charge pump overvoltage comparator</td>
<td>14.2 V</td>
<td>15 30</td>
<td>LOW LOW STANDBY</td>
</tr>
<tr>
<td>D1.7</td>
<td>VCP17_OV</td>
<td>VCP17 charge-pump overvoltage comparator</td>
<td>21 V</td>
<td>15 30</td>
<td>LOW LOW STANDBY</td>
</tr>
<tr>
<td>D1.8</td>
<td>NVDD6_UV</td>
<td>VDD6 undervoltage comparator (inverted)</td>
<td>5.2 5.4 V 6.22</td>
<td>10 40 6.18 Not changed Not changed Not changed</td>
<td></td>
</tr>
<tr>
<td>D1.9</td>
<td>VDD6_OV</td>
<td>VDD6 overvoltage comparator</td>
<td>7.8 8.2 V 6.23</td>
<td>10 40 6.18 Not changed Not changed Not changed</td>
<td></td>
</tr>
<tr>
<td>D1.10</td>
<td>NVDD5_UV</td>
<td>VDD5 undervoltage comparator (inverted)</td>
<td>4.5 4.85 V 6.8</td>
<td>10 40 6.18 Not changed Not changed Not changed</td>
<td></td>
</tr>
<tr>
<td>D1.11</td>
<td>VDD5_OV</td>
<td>VDD5 overvoltage comparator</td>
<td>5.2 5.45 V 6.10</td>
<td>10 40 6.18 Not changed LOW Not changed</td>
<td></td>
</tr>
<tr>
<td>D1.12</td>
<td>NVDD3/5_UV</td>
<td>VDD3/5 undervoltage comparator; 3.3-V setting (inverted)</td>
<td>3 3.17 V 6.12</td>
<td>10 40 6.18 LOW LOW RESET</td>
<td></td>
</tr>
<tr>
<td>D1.13</td>
<td>VDD3/5_OV</td>
<td>VDD3/5 overvoltage comparator; 3.3-V setting</td>
<td>3.43 3.6 V 6.14</td>
<td>10 40 6.18 Not changed LOW Not changed</td>
<td></td>
</tr>
<tr>
<td>D1.14</td>
<td>NVDD1_UV</td>
<td>VDD1 undervoltage comparator (inverted)</td>
<td>0.94 0.98 VDD1 6.16</td>
<td>10 40 6.18 Not changed when NMASK_VDD1_UV_OV = 0 (default config) Not changed when NMASK_VDD1_UV_OV = 0 (default config) Not changed when NMASK_VDD1_UV_OV = 0 (default config)</td>
<td></td>
</tr>
<tr>
<td>D1.15</td>
<td>VDD1_OV</td>
<td>VDD1 overvoltage comparator</td>
<td>1.03 1.06 VDD1 6.17</td>
<td>10 40 6.18 Not changed Not changed (default config) Not changed</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
- NMASK_VDD1_UV_OV = 0 (default config)
### Table 5-2. Internal Error Signals (continued)

<table>
<thead>
<tr>
<th>DMUX POS. NO.</th>
<th>SIGNAL NAME</th>
<th>DETECTIVE CONDITION (THRESHOLD LEVEL)</th>
<th>DEGLITCH TIME TO SET FLAG (µs)</th>
<th>DEVICE STATE WHEN FLAG IS SET</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1.16</td>
<td>LOCLK</td>
<td>Loss-of-system-clock comparator</td>
<td>0.742</td>
<td>2.64 MHz</td>
</tr>
<tr>
<td>D3.4</td>
<td>CP_OV</td>
<td>Charge-pump overvoltage comparator</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>D3.5</td>
<td>NCP_UV</td>
<td>Charge-pump undervoltage comparator</td>
<td>VBAT + 6</td>
<td>V</td>
</tr>
<tr>
<td>D3.8</td>
<td>CP_DIFF3V</td>
<td>Indicates VCP-VBATP &gt; 3 V</td>
<td>VBAT + 3</td>
<td>V</td>
</tr>
<tr>
<td>D3.10</td>
<td>NVBAT_UV</td>
<td>VBAT undervoltage comparator</td>
<td>4.2</td>
<td>4.5 V</td>
</tr>
<tr>
<td>D3.11</td>
<td>VBATP_OV</td>
<td>VBAT overvoltage comparator</td>
<td>34.7</td>
<td>36.7 V</td>
</tr>
<tr>
<td>D3.12</td>
<td>VDDS_OT</td>
<td>VDD5 overtemperature</td>
<td>175</td>
<td>210 °C</td>
</tr>
<tr>
<td>D3.13</td>
<td>VDD3/5_OT</td>
<td>VDD3/5 overtemperature</td>
<td>175</td>
<td>210 °C</td>
</tr>
<tr>
<td>D3.14</td>
<td>VSOUT1_OT</td>
<td>VSOUT1 overtemperature</td>
<td>175</td>
<td>210 °C</td>
</tr>
<tr>
<td>D3.15</td>
<td>VDDS_CL</td>
<td>VDD5 current-limit</td>
<td>350</td>
<td>650 mA</td>
</tr>
<tr>
<td>D3.16</td>
<td>VDD3/5_CL</td>
<td>VDD3/5 current-limit</td>
<td>350</td>
<td>650 mA</td>
</tr>
<tr>
<td>D4.2</td>
<td>VSOUT1_CL</td>
<td>VSOUT1 current-limit</td>
<td>100</td>
<td>500 mA</td>
</tr>
<tr>
<td>D3.17</td>
<td>NVSOUT1_UV</td>
<td>VSOUT1 undervoltage comparator</td>
<td>0.88</td>
<td>0.94 V</td>
</tr>
<tr>
<td>D4.3</td>
<td>VSOUT1_OV</td>
<td>VSOUT1 overvoltage comparator</td>
<td>1.06</td>
<td>1.12 VSOUT1</td>
</tr>
<tr>
<td>D4.4</td>
<td>NDVDD0_UV</td>
<td>DVDD undervoltage comparator (inverted)</td>
<td>2.472</td>
<td>V</td>
</tr>
<tr>
<td>D4.5</td>
<td>DVDD_OV</td>
<td>DVDD overvoltage comparator</td>
<td>3.501</td>
<td>V</td>
</tr>
<tr>
<td>D4.6</td>
<td>VS_TRK_MODE</td>
<td>VSOUT1 in track-mode indication</td>
<td>1.2</td>
<td>5.3a</td>
</tr>
<tr>
<td>D4.7</td>
<td>VMON_TRIM_ERR</td>
<td>VMON trim error</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(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.
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 µs. 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.

Figure 5-3. Analog BIST Run States

(1) For impact to the device state if any ABIST function has a FAIL, see Section 5.4.19.
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 (±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 TPS65381-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 causes 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**

<table>
<thead>
<tr>
<th>VOLTAGE RAIL</th>
<th>OVERTEMPERATURE PROTECTION</th>
<th>OVERCURRENT PROTECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>THRESHOLD (°C)</td>
<td>IMPACT ON DEVICE BEHAVIOR</td>
</tr>
<tr>
<td>VDD6</td>
<td>175 to 210 (shared with VDD6 and VDD3/5)</td>
<td>Sets VDD3/5_OT (in SAFETY_STAT_1) when NMASK_VDD3/5_OT = 1,STANDBY state when NMASK_VDD3/5_OT = 0, disables VDD3/5, RESET when VDD3/5 reaches UV level</td>
</tr>
<tr>
<td>VDD3/5</td>
<td>350 to 650 mA</td>
<td>Sets VDD3/5_ILIM (in SAFETY_STAT_1)</td>
</tr>
<tr>
<td>VDD5</td>
<td>175 to 210</td>
<td>Sets VDD5_OT (in SAFETY_STAT_1) when NMASK_VDD5_OT = 1, clears VDD5_EN (in SENS_CTRL) and VDD5 switched off, RESET state when NMASK_VDD5_OT = 0, overtemperature indicated in VDD5_OT</td>
</tr>
<tr>
<td>VDD1</td>
<td>None</td>
<td>N/A</td>
</tr>
<tr>
<td>VSOUT1</td>
<td>175 to 210</td>
<td>Sets VSOUT1_OT (in SAFETY_STAT_1) clears VSOUT1_EN (in SENS_CTRL) and VSOUT1 disabled</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>SIGNAL NUMBER</th>
<th>VOLTAGE RAIL or SIGNAL NAME</th>
<th>DESCRIPTION</th>
<th>SUPPLY RANGE[1]</th>
<th>DIVIDE RATIO</th>
<th>DIVIDE RATIO ACCURACY[2]</th>
<th>OUTPUT RESISTANCE (kΩ)</th>
<th>DIAG_MUX_SEL[7:0]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1</td>
<td>VDD5</td>
<td>Linear VDD5 regulator output</td>
<td>5.8 to 34 V</td>
<td>2</td>
<td>--2.25 % 0.75 %</td>
<td>20 50</td>
<td>0x01</td>
</tr>
<tr>
<td>A.2</td>
<td>VDD6</td>
<td>Switch mode preregulator</td>
<td>5.8 to 34 V</td>
<td>3</td>
<td>--3.75 % 0.5 %</td>
<td>30 100</td>
<td>0x02</td>
</tr>
<tr>
<td>A.3</td>
<td>VCP</td>
<td>Charge pump</td>
<td>5.8 to 18 V</td>
<td>13.5</td>
<td>--6.25 % 2.25 %</td>
<td>90 200</td>
<td>0x04</td>
</tr>
<tr>
<td>A.4</td>
<td>VSOUT1</td>
<td>Sensor supply voltage</td>
<td>5.8 to 34 V</td>
<td>4</td>
<td>--0.5 % 1.2 %</td>
<td>40 100</td>
<td>0x08</td>
</tr>
<tr>
<td>A.5</td>
<td>VBAT_SAFING</td>
<td>Battery (supply) input for monitoring (VMON) and BG2 functions</td>
<td>5.8 to 18 V</td>
<td>10</td>
<td>--5 % 0 %</td>
<td>125 200</td>
<td>0x10</td>
</tr>
<tr>
<td>A.6</td>
<td>VBATP</td>
<td>Battery (supply), main power supply</td>
<td>5.8 to 34 V</td>
<td>10</td>
<td>--5 % 5.5 %</td>
<td>125 200</td>
<td>0x20</td>
</tr>
<tr>
<td>A.7</td>
<td>MAIN_BG</td>
<td>Regulators band-gap reference</td>
<td>5.8 to 34 V</td>
<td>1</td>
<td>NA</td>
<td>3 15</td>
<td>0x40</td>
</tr>
<tr>
<td>A.8</td>
<td>VMON_BG</td>
<td>Voltage-monitor band gap</td>
<td>5.8 to 34 V</td>
<td>1</td>
<td>NA</td>
<td>3 15</td>
<td>0x80</td>
</tr>
</tbody>
</table>

(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 $I_{DIAG_OUT} \times$ 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.


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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>D1.1</td>
<td>RSV</td>
<td>Reserved, logic 0</td>
<td>000b</td>
<td>0000b</td>
</tr>
<tr>
<td>D1.2</td>
<td>NAVDD_UV</td>
<td>AVDD undervoltage comparator output (inverted)</td>
<td>000b</td>
<td>0001b</td>
</tr>
<tr>
<td>D1.3</td>
<td>BG_ERR1</td>
<td>VMON or main band gap is OFF</td>
<td>000b</td>
<td>0010b</td>
</tr>
<tr>
<td>D1.4</td>
<td>BG_ERR2</td>
<td>VMON or main band gap is OFF</td>
<td>000b</td>
<td>0011b</td>
</tr>
<tr>
<td>D1.5</td>
<td>NVCP12_UV</td>
<td>VCP12 charge-pump undervoltage comparator (inverted)</td>
<td>000b</td>
<td>0100b</td>
</tr>
<tr>
<td>D1.6</td>
<td>VCP12_OV</td>
<td>VCP12 charge-pump overvoltage comparator</td>
<td>000b</td>
<td>0101b</td>
</tr>
<tr>
<td>D1.7</td>
<td>VCP17_OV</td>
<td>VCP17 charge-pump overvoltage comparator</td>
<td>000b</td>
<td>0110b</td>
</tr>
<tr>
<td>D1.8</td>
<td>NVDD6_UV</td>
<td>VDD6 undervoltage comparator (inverted)</td>
<td>000b</td>
<td>0111b</td>
</tr>
<tr>
<td>D1.9</td>
<td>VDD6_OV</td>
<td>VDD6 overvoltage comparator</td>
<td>000b</td>
<td>1000b</td>
</tr>
<tr>
<td>D1.10</td>
<td>NVDD5_UV</td>
<td>VDD5 undervoltage comparator (inverted)</td>
<td>000b</td>
<td>1001b</td>
</tr>
<tr>
<td>D1.11</td>
<td>VDD5_OV</td>
<td>VDD5 overvoltage comparator</td>
<td>000b</td>
<td>1010b</td>
</tr>
<tr>
<td>D1.12</td>
<td>NVDD3_5_UV</td>
<td>VDD3/5 undervoltage comparator (inverted)</td>
<td>000b</td>
<td>1011b</td>
</tr>
<tr>
<td>D1.13</td>
<td>VDD3_5_OV</td>
<td>VDD3/5 overvoltage comparator</td>
<td>000b</td>
<td>1100b</td>
</tr>
<tr>
<td>D1.14</td>
<td>NVDD1_UV</td>
<td>VDD1 undervoltage comparator</td>
<td>000b</td>
<td>1101b</td>
</tr>
<tr>
<td>D1.15</td>
<td>VDD1_OV</td>
<td>VDD1 overvoltage comparator</td>
<td>000b</td>
<td>1110b</td>
</tr>
<tr>
<td>D1.16</td>
<td>LOCLK</td>
<td>Loss-of-system-clock comparator</td>
<td>000b</td>
<td>1111b</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>D3.1</td>
<td>RSV</td>
<td>Reserved, logic 0</td>
<td>010b</td>
<td>0000b</td>
</tr>
<tr>
<td>D3.2</td>
<td>DFT</td>
<td>Signal reserved for production test</td>
<td>010b</td>
<td>0001b</td>
</tr>
<tr>
<td>D3.3</td>
<td>DFT</td>
<td>Signal reserved for production test</td>
<td>010b</td>
<td>0010b</td>
</tr>
<tr>
<td>D3.4</td>
<td>CP_OV</td>
<td>Charge-pump overvoltage comparator</td>
<td>010b</td>
<td>0011b</td>
</tr>
<tr>
<td>D3.5</td>
<td>NCP_UV</td>
<td>Charge-pump undervoltage comparator (inverted)</td>
<td>010b</td>
<td>0100b</td>
</tr>
<tr>
<td>D3.6</td>
<td>CP_PH1</td>
<td>Charge-pump switching phase 1</td>
<td>010b</td>
<td>0101b</td>
</tr>
<tr>
<td>D3.7</td>
<td>CP_PH2</td>
<td>Charge-pump switching phase 2</td>
<td>010b</td>
<td>0110b</td>
</tr>
<tr>
<td>D3.8</td>
<td>CP_DIFF3V</td>
<td>Indicates VCP-VBATP &gt; 3 V</td>
<td>010b</td>
<td>0111b</td>
</tr>
<tr>
<td>D3.9</td>
<td>DFT</td>
<td>Signal reserved for production test</td>
<td>010b</td>
<td>1000b</td>
</tr>
<tr>
<td>D3.10</td>
<td>NVBAT_UV</td>
<td>VBAT undervoltage comparator (inverted)</td>
<td>010b</td>
<td>1001b</td>
</tr>
<tr>
<td>D3.11</td>
<td>VBATP_OV</td>
<td>VBAT overvoltage comparator</td>
<td>010b</td>
<td>1100b</td>
</tr>
<tr>
<td>D3.12</td>
<td>VDD5_OT</td>
<td>VDD5 overtemperature</td>
<td>010b</td>
<td>1101b</td>
</tr>
<tr>
<td>D3.13</td>
<td>VDD3/5_OT</td>
<td>VDD3/5 overtemperature</td>
<td>010b</td>
<td>1110b</td>
</tr>
<tr>
<td>D3.14</td>
<td>VSOUT1_OT</td>
<td>VSOUT1 overtemperature</td>
<td>010b</td>
<td>1111b</td>
</tr>
<tr>
<td>D3.15</td>
<td>VDD5_CL</td>
<td>VDD5 current-limit</td>
<td>010b</td>
<td>1111b</td>
</tr>
<tr>
<td>D3.16</td>
<td>VDD3_CL</td>
<td>VDD3 current-limit</td>
<td>010b</td>
<td>1111b</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>D4.1</td>
<td>RSV</td>
<td>Reserved, logic 0</td>
<td>011b</td>
<td>0000b</td>
</tr>
<tr>
<td>D4.2</td>
<td>VSOUT1_CL</td>
<td>VSOUT1 current-limit</td>
<td>011b</td>
<td>0001b</td>
</tr>
<tr>
<td>D4.3</td>
<td>NVSOUT1_UV</td>
<td>VSOUT1 undervoltage comparator (inverted)</td>
<td>011b</td>
<td>0010b</td>
</tr>
<tr>
<td>D4.4</td>
<td>VSOUT1_OV</td>
<td>VSOUT1 overvoltage comparator</td>
<td>011b</td>
<td>0011b</td>
</tr>
<tr>
<td>D4.5</td>
<td>NDVDD_UV</td>
<td>DVDD undervoltage comparator (inverted)</td>
<td>011b</td>
<td>0100b</td>
</tr>
<tr>
<td>D4.6</td>
<td>DVDD_OV</td>
<td>DVDD overvoltage comparator</td>
<td>011b</td>
<td>0101b</td>
</tr>
<tr>
<td>D4.7</td>
<td>RSV</td>
<td>Reserved</td>
<td>011b</td>
<td>0110b</td>
</tr>
<tr>
<td>D4.8</td>
<td>VS_TRK_MODE</td>
<td>VSOUT1 in track-mode indication</td>
<td>011b</td>
<td>0111b</td>
</tr>
<tr>
<td>D4.9</td>
<td>VMON_TRIM_ERR</td>
<td>VMON trim error</td>
<td>011b</td>
<td>1000b</td>
</tr>
<tr>
<td>D4.10-16</td>
<td>RSV</td>
<td>Reserved</td>
<td>011b</td>
<td>1001b-1111b</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>D5.1</td>
<td>RSV</td>
<td>Reserved, logic 0</td>
<td>111b</td>
<td>0000b</td>
</tr>
<tr>
<td>D5.2</td>
<td>TI_TEST_MODE</td>
<td>TI production test mode indication</td>
<td>111b</td>
<td>0001b</td>
</tr>
<tr>
<td>D5.3-16</td>
<td>DFT</td>
<td>Signal reserved for production test</td>
<td>111b</td>
<td>0010b-1111b</td>
</tr>
</tbody>
</table>
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.

---

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

<table>
<thead>
<tr>
<th>WATCHDOG FAIL COUNTER WD_FAIL_CNT[2:0]</th>
<th>000b THROUGH 100b</th>
<th>101b THROUGH 111b</th>
<th>111b</th>
</tr>
</thead>
<tbody>
<tr>
<td>The watchdog status is based on the WD_FAIL_CNT[2:0] value.</td>
<td>Watchdog in-range</td>
<td>Watchdog is out-of-range</td>
<td>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 &quot;bad&quot; or &quot;time-out&quot; event to the watchdog</td>
</tr>
</tbody>
</table>

---

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.

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

where
- The bits RT[6:0] are located in the WD_WIN1_CFG SPI register.

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

where
- The bits RW[4:0] are located in the WD_WIN2_CFG SPI register.

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

where
- The bits RW[4:0] are located in the WD_WIN2_CFG SPI register.

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:

$$t_{SEQUENCE\_MIN} = t_{TIMEOUT\_MIN} = t_{WIN1\_MIN} + t_{WIN2\_MIN}$$

$$t_{SEQUENCE\_MAX} = t_{TIMEOUT\_MAX} = t_{WIN1\_MAX} + t_{WIN2\_MAX}$$

The watchdog uses the internal system clock of the device (±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 (±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 TPS65381-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 \( t_{\text{WIN1}} \) and \( t_{\text{WIN2}} \) 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, \( t_{\text{WD\_pulse\_max}} \) (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 \( t_{\text{WIN2}} \) 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 \( t_{\text{WD\_pulse}} \) 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 \( t_{\text{WD\_pulse\_max}} \) 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:

\[ t_{WCW\_MIN} (Trigger\ mode) = t_{WIN1\_MIN} \]

where

- WCW is a watchdog CLOSE window

\[ t_{WCW\_MAX} (Trigger\ mode) = t_{WIN1\_MAX} \]

where

- WCW is a watchdog CLOSE window

\[ t_{WOW\_MIN} (Trigger\ mode) = t_{WIN2\_MIN} \]

where

- WOW is a watchdog OPEN window

\[ t_{WOW\_MIN} (Trigger\ mode) = t_{WIN2\_MIN} \]

where

- WOW is a watchdog OPEN window

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

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.
**Case No. 1:** Time-Out Event

A. When a **time-out event** occurs, 1 system clock-cycle (250 ns, typical) later, the next watchdog sequence begins.

B. **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.

C. 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:

\[ t_{WOW\_MIN\_\text{(Q&A mode)}} = t_{WIN1\_MIN} \]

where
- WOW is a watchdog OPEN window

\[ t_{WOW\_MAX\_\text{(Q&A mode)}} = t_{WIN1\_MAX} \]

where
- WOW is a watchdog OPEN window

\[ t_{WCW\_MIN\_\text{(Q&A mode)}} = t_{WIN2\_MIN} \]

where
- WCW is a watchdog CLOSE window

\[ t_{WCW\_MIN\_\text{(Q&A mode)}} = t_{WIN2\_MIN} \]

where
- WCW is a watchdog CLOSE window

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.
The first three correct answer bytes (responses) may be scheduled in WINDOW 1 or WINDOW 2. The first three answer bytes must be in the correct order (sequence):
- Answer-3 (WD_TOKEN_RESP_3) followed by
- Answer-2 (WD_TOKEN_RESP_2) followed by
- Answer-1 (WD_TOKEN_RESP_1)

After WINDOW 1 time elapses, WINDOW 2 begins.

The MCU needs to write the answer bytes (responses) to WD_ANSWER register.

After the MCU writes the fourth answer byte (Answer-0) to the WD_ANSWER register, the watchdog generates the next question (token) after which next watchdog sequence begins.

(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

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)

4-bit SEED Value Loaded when the device goes to the RESET state
( Programmable Through TOKEN_SEED[3:0] )
( Default Value 4'b0000 )

(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

<table>
<thead>
<tr>
<th>QUESTION (TOKEN) IN WD_TOKEN_VALUE REGISTER</th>
<th>WD ANSWER (TO BE WRITTEN INTO WD_ANSW REGISTER)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Answer-3 (WD_TOKEN_RESP_3)</td>
</tr>
<tr>
<td>0h</td>
<td>FFh</td>
</tr>
<tr>
<td>1h</td>
<td>80h</td>
</tr>
<tr>
<td>2h</td>
<td>19h</td>
</tr>
<tr>
<td>3h</td>
<td>A6h</td>
</tr>
<tr>
<td>4h</td>
<td>75h</td>
</tr>
<tr>
<td>5h</td>
<td>3Ah</td>
</tr>
<tr>
<td>6h</td>
<td>63h</td>
</tr>
<tr>
<td>7h</td>
<td>2Ch</td>
</tr>
<tr>
<td>8h</td>
<td>D2h</td>
</tr>
<tr>
<td>9h</td>
<td>9Dh</td>
</tr>
<tr>
<td>Ah</td>
<td>4Ch</td>
</tr>
<tr>
<td>Bh</td>
<td>8Bh</td>
</tr>
<tr>
<td>Ch</td>
<td>58h</td>
</tr>
<tr>
<td>Dh</td>
<td>17h</td>
</tr>
<tr>
<td>Eh</td>
<td>4Eh</td>
</tr>
<tr>
<td>Fh</td>
<td>01h</td>
</tr>
</tbody>
</table>

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 reset.

- 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

<table>
<thead>
<tr>
<th>All MCU Answer Bytes Correct?</th>
<th>Answer-0 Arrived During WINDOW 2 (CLOSE)</th>
<th>Answer-0 Arrived During WINDOW 1 (OPEN)</th>
<th>Time-out Occurred While Waiting for Answer?</th>
<th>WINDOW 1 or WINDOW 2 Duration Changed?</th>
<th>WD_CFG_CHG</th>
<th>SEQ_ERR</th>
<th>TIME_OUT</th>
<th>ANSWER_EARLY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Yes (first 3 Answer-x)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
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<td>No</td>
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<td>1</td>
<td>0</td>
</tr>
<tr>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Yes</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
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 TPS65381-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 TPS65381-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 µs to 1.28 ms (typical), with 5-µs steps (±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:

\[
\begin{align*}
 t_{\text{TMS570 LOW MIN}} &= (\text{PWML}[7:0]) \times 5 \text{ µs} \times 0.95 \\
 t_{\text{TMS570 LOW MAX}} &= (\text{PWML}[7:0] + 1) \times 5 \text{ µs} \times 1.05
\end{align*}
\]

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 ±5%).
- After reinitialization, the low-pulse counter restarts one system clock-cycle (250 ns ±5%).
- The low-pulse duration counter increases every 5 µs (with ±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 ± 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.
Case No. 1: Error event occurred, but MCU recovered or corrected the failure in the allowed time interval by sending ERROR pin reset request which returned the input to ERROR/WDI high.

Case No. 2: Error event occurred and MCU did NOT recover and/or was not able to correct the problem within the allowed time interval.

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 µs to 3.8 ms (typical), with 15-µs resolution steps (±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 times are as follows:

\[
\begin{align*}
 t_{PWM_{HIGH\_MIN}} &= (PWMH[7:0]) \times 15 \mu s \times 0.95 \\
 t_{PWM_{HIGH\_MAX}} &= (PWMH[7:0] + 1) \times 15 \mu s \times 1.05 \\
 t_{PWM_{LOW\_MIN}} &= (PWML[7:0]) \times 15 \mu s \times 0.95 \\
 t_{PWM_{LOW\_MAX}} &= (PWML[7:0] + 1) \times 15 \mu s \times 1.05
\end{align*}
\]

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

**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 ±5%).
- After reinitialization, the low-pulse counter restarts after one system clock-cycle (250 ns ±5%).
- The low-pulse duration counter increases every 15 µs (±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 ±5%).
- After reinitialization, the high-pulse counter restarts after one system clock-cycle (250 ns ±5%).
- The high-pulse duration counter increases every 15 µs (with ± 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.
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 ±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 TPS65381-Q1 device in the DIAGNOSTIC state, clearing the CFG_CRC_EN bit to 0 brings the TPS65381-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

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

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:

<table>
<thead>
<tr>
<th>63</th>
<th>Byte 7</th>
<th>Byte 6</th>
<th>Byte 5</th>
<th>Byte 4</th>
<th>Byte 3</th>
<th>Byte 2</th>
<th>Byte 1</th>
<th>Byte 0</th>
</tr>
</thead>
</table>

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

Table 5-14 lists some CRC calculation examples.

### Table 5-14. CRC Calculation Examples

<table>
<thead>
<tr>
<th>64-BIT BUS ORDERING VALUE</th>
<th>CRC-8 RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000 0000 0000 0000h</td>
<td>DBh</td>
</tr>
<tr>
<td>FFFF FFFF FFFF FFFFh</td>
<td>0Ch</td>
</tr>
<tr>
<td>0A0A 0505 0A0A 0505h</td>
<td>D4h</td>
</tr>
<tr>
<td>0505 0A0A 0505 0A0Ah</td>
<td>17h</td>
</tr>
<tr>
<td>A0A0 5050 A0A0 5050h</td>
<td>2Bh</td>
</tr>
<tr>
<td>0A23 E000 18FE 7B80h</td>
<td>1Bh</td>
</tr>
</tbody>
</table>
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 CRC 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 µs 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 µs 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.

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 µs) 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.
The signal deglitch time is defined for each undervoltage or overvoltage condition as given in Section 4.

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 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 recrank (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 µs, 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] × 2) + 1] × 22 ms.

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] × 2) + 1] × 22 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 TPS65381-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>
<thead>
<tr>
<th>BIT</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>FUNCTION</td>
<td>CMD6</td>
<td>CMD5</td>
<td>CMD4</td>
<td>CMD3</td>
<td>CMD2</td>
<td>CMD1</td>
<td>CMD0</td>
<td>PARITY</td>
</tr>
</tbody>
</table>

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_{hics}) 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

<table>
<thead>
<tr>
<th>BIT</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>FUNCTION</td>
<td>DATA7</td>
<td>DATA6</td>
<td>DATA5</td>
<td>DATA4</td>
<td>DATA3</td>
<td>DATA2</td>
<td>DATA1</td>
<td>DATA0</td>
</tr>
</tbody>
</table>

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_{hc}) 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

<table>
<thead>
<tr>
<th>BIT</th>
<th>R7</th>
<th>R6</th>
<th>R5</th>
<th>R4</th>
<th>R3</th>
<th>R2</th>
<th>R1</th>
<th>R0</th>
</tr>
</thead>
</table>

| 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 TPS65381-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>
<thead>
<tr>
<th>BIT</th>
<th>R7</th>
<th>R6</th>
<th>R5</th>
<th>R4</th>
<th>R3</th>
<th>R2</th>
<th>R1</th>
<th>R0</th>
</tr>
</thead>
<tbody>
<tr>
<td>FUNCTION</td>
<td>R7</td>
<td>R6</td>
<td>R5</td>
<td>R4</td>
<td>R3</td>
<td>R2</td>
<td>R1</td>
<td>R0</td>
</tr>
</tbody>
</table>

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

Table 5-18. Device SPI Data Response
• 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

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

(1) All commands have even parity.
Table 5-19. SPI Command Table (continued)

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

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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>1b</td>
<td>1b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>1b</td>
</tr>
</tbody>
</table>

D[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**

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSV</td>
<td>RSV</td>
<td>RSV</td>
<td>RSV</td>
<td>RSV</td>
<td>RSV</td>
<td>CANWU_L</td>
<td>IGN</td>
</tr>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDD_3_5_SEL</td>
<td>NMASK_VDD1_UV_OV</td>
<td>RSV</td>
<td>RSV</td>
<td>RSV</td>
<td>RSV</td>
<td>RSV</td>
<td>RSV</td>
</tr>
<tr>
<td>X</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

**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](image-url)

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMASK_VDD3/5_OT</td>
<td>NMASK_VDD5_OT</td>
<td>MASK_VBATP_OV</td>
<td>POST_RUN_RST</td>
<td>RSV</td>
<td>RSV</td>
<td>RSV</td>
<td>RSV</td>
</tr>
<tr>
<td>1b</td>
<td>1b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>VBATP_OV</td>
<td>VBATP_UV</td>
<td>VCP17_OV</td>
<td>VCP12_OV</td>
<td>VCP12_UV</td>
<td>AVDD_VMON_ERR</td>
<td>BG_ERR2</td>
<td>BG_ERR1</td>
</tr>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td></td>
</tr>
</tbody>
</table>

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

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

- Set to 1 when a VCP17 overvoltage condition is detected
- Cleared to 0 if an overvoltage condition is no longer present

- 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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDD6_OV</td>
<td>VDD6_UV</td>
<td>VDD5_OV</td>
<td>VDD5_UV</td>
<td>VDD3/5_OV</td>
<td>VDD3/5_UV</td>
<td>VDD1_OV</td>
<td>VDD1_UV</td>
</tr>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

- **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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDD5_ILIM</td>
<td>VDD3/5_ILIM</td>
<td>VSOUT1_UV</td>
<td>VSOUT1_OV</td>
<td>RSV</td>
<td>VSOUT1_OT</td>
<td>VDD5_OT</td>
<td>VDD_3_5_OT</td>
</tr>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

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.

- 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

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

D[3] RSV
- This bit was previously the VSOUT1_ILIM bit: VSOUT1 sensor-supply current-limit status bit
- Use diagnostic output pin, DIAG_OUT, with the digital MUX setting for VSOUT1_CL to monitor current-limit status for VSOUT1

- 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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>1b</td>
<td>0b</td>
<td>1b</td>
</tr>
</tbody>
</table>

- **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.
- **D[4]** **EE_CRC_ERR**: EEPROM 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**

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSV</td>
<td>RSV</td>
<td>NRES_ERR</td>
<td>LBIST_ERR</td>
<td>ABIST_ERR</td>
<td>ABIST_ERR</td>
<td>LBIST_RUN</td>
<td>ABIST_RUN</td>
</tr>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

**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 µs 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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPI_ERR[1]</td>
<td>SPI_ERR[0]</td>
<td>LOCLK</td>
<td>RSV</td>
<td>MCU_ERR</td>
<td>WD_ERR</td>
<td>ENDRV_ERR</td>
<td>TRIM_ERR_VMON</td>
</tr>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

D[7:6] SPI_ERR[1:0]: SPI error-status bits
- 00b = No error
- 01b = SPI SDO error (mismatch on SDO output)
- 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

- 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

- 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 µs 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**

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>1b</td>
<td>1b</td>
<td></td>
</tr>
</tbody>
</table>

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**

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

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 × SAFE_TO[2:0] + 1) × 22 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 DEV_ERR_CNT[3:0] < 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 (SAFE_TO[2:0] × 2 + 1) × 22 ms  
  - Device remains locked in the SAFE state when the DEV_ERR_CNT[3:0] counter reaches SAFE_LOCK_THR[3:0] + 1 value.  
- When the NO_SAFE_TO bit (SAFETY_FUNC_CFG register, bit 7) is cleared to 0:  
  - While DEV_ERR_CNT[3:0] < 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 (SAFE_TO[2:0] × 2 + 1) × 22 ms  
  - When the DEV_ERR_CNT[3:0] counter reaches 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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIST_DEG_CN</td>
<td>BIST_DEG_CN</td>
<td>AUTO_BIST_DIS</td>
<td>EE_CRC_CHK</td>
<td>RSV</td>
<td>LBIST_EN</td>
<td>ABIST_EN</td>
<td>ABIST_EN</td>
</tr>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

- **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 µs (with the minimum setting at 15 µs and the maximum setting at 60 µs):  
    \[ \text{bist\_deglitch} = (\text{BIST\_DEG\_CNT}[1:0] + 1) \times 15 \text{ µs} \]  
  - 15-µs 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_CRCCHK:** 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](image)

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFG_CRC_EN</td>
<td>RSV</td>
<td>ENABLE_DRV</td>
<td>RSV</td>
<td>RSV</td>
<td>NO_ERROR</td>
<td>DIAG_EXIT_MASK</td>
<td>DIAG_EXIT</td>
</tr>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>1b</td>
<td>0b</td>
<td>1b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO_SAFE_TO</td>
<td>ERROR_CFG</td>
<td>WD_CFG</td>
<td>IGN_PWRL</td>
<td>WD_RST_EN</td>
<td>DIS_NRES_MON</td>
<td>RSV</td>
<td>VDD_3_5_SEL</td>
</tr>
<tr>
<td>1b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>1b</td>
<td>0b</td>
<td>X</td>
</tr>
</tbody>
</table>

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.

- 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 5.5.4.13 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

- 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

- 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 writable 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*

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td></td>
</tr>
</tbody>
</table>

**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*

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1b</td>
<td>0b</td>
<td>1b</td>
<td>0b</td>
<td>1b</td>
<td>0b</td>
<td>0b</td>
<td></td>
</tr>
</tbody>
</table>

**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, $t_{PWM\_HIGH\_PWM}$. (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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>1b</td>
<td>1b</td>
<td>1b</td>
<td>0b</td>
<td>1b</td>
<td></td>
</tr>
</tbody>
</table>

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-µs resolution
    Use Equation 19 and Equation 20 to calculate the minimum and maximum values for the LOW pulse duration, \( t_{PWM\_LOW} \).
    (15-µs time reference has 5% accuracy coming from 4-MHz internal oscillator)
  ● When ERR_CFG bit is 1 (TMS570 mode): error low duration with 5-µs resolution
    Use Equation 15 and Equation 16 to calculate the minimum and maximum values for the LOW duration, \( t_{TMS570\_LOW} \).
    (5-µs 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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>1b</td>
<td>1b</td>
<td>1b</td>
<td>1b</td>
</tr>
</tbody>
</table>

D[7:4] RSV
D[3:0] PWDT_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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>1b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

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

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)

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>1b</td>
<td>1b</td>
<td>1b</td>
<td>1b</td>
<td>1b</td>
<td>1b</td>
<td>1b</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>1b</td>
<td>1b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

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**

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

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 byte
- 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**

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>WD_ANSW_C NT[1]</td>
<td>WD_ANSW_C NT[0]</td>
<td>ANSWER_ERR</td>
<td>WD_WRONG_CFG</td>
<td>WD_CFG_CHG</td>
<td>SEQ_ERR</td>
<td>TIME_OUT</td>
<td>ANSWER_EARLY</td>
</tr>
<tr>
<td>1b</td>
<td>1b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

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.

- 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**

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

**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**

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSV</td>
<td>RSV</td>
<td>RSV</td>
<td>VDD5_EN</td>
<td>RSV</td>
<td>RSV</td>
<td>RSV</td>
<td>VSOUT1_EN</td>
</tr>
<tr>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>1b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
</tbody>
</table>

**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

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.

6.1 Application Information

The TPS65381-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 TPS65381-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 9.2.1.
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 Ω 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. \(R_{VSFB1}\) and \(R_{VSFB2}\) configure the VSOUT1 voltage
   - Pin 16 (VSIN) to be connected either to pin 27 (VDD6) for VSOUT1 ≤ 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. \(R_{RSEXT}\) 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.

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

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.
6.2.2.2 VDD1 Linear Controller

The microprocessor used with the TPS65381-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.

\[
R_2 = \left( \frac{V_{DD1} \times R_1}{V_{DD1\_SENSE}} \right) - R_1 = \left( \frac{1.23 \text{ V} \times 80.6 \text{ } \Omega}{0.8 \text{ V}} \right) - 80.6 \text{ } \Omega = 43.3 \text{ } \Omega
\] (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.
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.
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_{VSFB1} 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_{VSFB2}.

\[
R_{VSFB2} = (\frac{[\text{VSOUT1} \times R_{VSFB1}]}{\text{VTRACK}}) - R_{VSFB1} = (\frac{[6 \text{ V} \times 3.3 \text{ kΩ}]}{3.3 \text{ V}}) - 3.3 \text{ kΩ} = 2.7 \text{ kΩ}
\]

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 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)](image)
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 $R_{VSFB2}$.

$$R_{VSFB2} = \left( \frac{\text{VSOUT1} \times R_{VSFB1}}{\text{VTRACK}} \right) - R_{VSFB1} = \left( \frac{9 \text{ V} \times 3.3 \text{ kΩ}}{5 \text{ V}} \right) - 3.3 \text{ kΩ} = 2.64 \text{ kΩ} \tag{24}$$

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.
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 \((V_{\text{ref}})\) 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 kΩ for the RVSFB1 resistor to balance the current through the resistor divider for reasonable bias current and reasonable losses. Use Equation 25 to calculate the resistance of \(R_{\text{VSFB2}}\).

\[
R_{\text{VSFB2}} = \left(\frac{\text{VSOUT1} \times R_{\text{VSFB1}}}{V_{\text{ref}}} \right) - R_{\text{VSFB1}} = \left(\frac{4.5 \text{ V} \times 3.3 \text{ k}\Omega}{2.5 \text{ V}} \right) - 3.3 \text{ k}\Omega = 2.64 \text{ k}\Omega
\] (25)

Select the standard value of 2.7 kΩ.

**NOTE**
The tolerance of the \(R_{\text{VSFB1}}\) and \(R_{\text{VSFB2}}\) 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-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 6-7 shows this configuration.

\[
R_{\text{VSFB2}} = 2.7 \text{ k}\Omega
\]

\[
R_{\text{VSFB1}} = 3.3 \text{ k}\Omega
\]

**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>
<thead>
<tr>
<th>FIGURE TITLE</th>
<th>FIGURE NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPI SDO Buffer Source and Sink Current</td>
<td>Figure 4-3</td>
</tr>
<tr>
<td>VDD6 BUCK Efficiency</td>
<td>Figure 4-4</td>
</tr>
</tbody>
</table>
6.3 System Examples

Figure 6-8. Electrical Power-Steering Example
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).

B. The ENDRV output can be configured as either as ENABLE for the external power stage (typical use), or optionally as warm-RESET for the TMS570.

Figure 6-9. Example TPS65381-Q1 With TI's TMS570LS
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 TPS65381-Q1 With TI's TMS470 (Using an Internal MCU Core Supply)
Watchdog Function in Q&A Mode
Software Implementation Example
(according to implementation on TMS570 MCU)

Start

Supply

VBAT, VBATP

STANDBY

State

(Initialization)

NO

YES

RES E

Extension

Complete

NO

YES

DIAGNOSTIC

State

(Diagnostic)

Start WD

Synchronization

(Diagnostic state)

Read Pending WD

Question (Token)

Send First Three Answer

Bytes (Diagnostic state)

Send last Answer Byte

(Answer 0)

Read WD Status

Register

(Answer 0)

WD Service

Routine correct?

NO

YES

Set WD_RST_EN bit

ACTIVE State

NO

YES

WD_FAIL_CNT

is decremented below 0?

Enable END DRV

(ACTIVE state)

Check END RV, ERR bit

(ACTIVE state)

NO

YES

No

NO

YES

NO

YES

END RV, ERR bit is 0?

Continue to monitor and control main safing function

Figure 6-11. Software Flowchart for Configuring and Synchronizing the MCU with the Watchdog in Q&A Mode

TPS65381 for desired settings including watchdog configuration:
- Set Watchdog to desired mode (Trigger or Q&A Mode, this example, set to Q&A Mode)
- Set desired WINDOW1 and WINDOW2 time periods
- Configure MCU-timer to be enabled when the watchdog time-out event is detected (if re-synchronizing on a watchdog time-out event is desired)
- Configured MCU-timer: set timer(s) and software to support:
  - Within WINDOW 1 or WINDOW 2: read or calculate the question, calculate and send the first three Answer-x bytes
  - Within WINDOW 2: calculate and send the fourth Answer-0 byte

Synchronize the MCU to the TPS65381 watchdog: Write to WD_WIN1_CFG or WD_WIN2_CFG register ensuring the setting is the desired time period for watchdog operation. This write to WD_WIN1_CFG will start a new watchdog sequence (and increment the watchdog fail counter). The MCU timer should start in sync with this write so the MCU timer and the device watchdog timer are synchronized.

Initial Watchdog Synchronization Routine

Read question (WD_TOKEN_VALUE register bits TOKEN(3:0))
After each sent answer byte, confirm that the response was correct by reading the WD_STATUS register to confirm the following:
- No status bits mapped to bits D5, D4, D2, or D0 should be set. Bit D3, WD_CFG.CHG, is set when WIN1 or WIN2 timing is changed. Bit D1, TIME_OUT, is likely set due to no watchdog service at this point in time.
- WD_ANSW_CNT[1:0] bits should be updated with each provided answer-byte
- Write to WD_ANSWER register

Within WINDOW 1: read the WD_STATUS register to check if bits D4 and D1 are not set. Bits D3 and D1 should clear as the configuration is stable and the watchdog is being serviced.
- Observe WD_ANSW_CNT[1:0] to make sure it updates after each answer
- Observe WD_FAIL_CNT[2:0] in the SAFETY_STAT_3 register is decremented

Confirm the responses from the expected watchdog service routine:
- Read watchdog question
- Respond with correct answers (with correct sequence and timing)
  - Observe watchdog status bits in WD_STATUS register are not set (bits D5:D0)
  - Observe corresponding WD_ANSW_CNT[1:0] update after each answer-byte
  - Observe WD_FAIL_CNT[2:0] in the SAFETY_STAT_2 register are decremented

- Read watchdog question
- Respond with watchdog in-correct answers (wrong sequence or wrong timing or wrong answer)
  - Observe corresponding WD status bits in WD_STATUS register is set (bits D5:D0)
  - Observe WD_FAIL_CNT[2:0] in the SAFETY_STAT_2 register are incremented

- Write to the register SAFETY_FUNC_CFG
  - WD_FAIL_CNT[2:0] < 5 and correct operation of the watchdog has been confirmed in previous steps

  - Write to the register SAFETY_FUNC_CFG
    - WD_FAIL_CNT[2:0] = 0
    - WD_RST_EN[3] bit is set to 1
    - WD_STS (in the SAFETY_CHECK_CTRL register)

  - Disable the safing path when the WD_FAIL_CNT[2:0] reaches a count of 5 (ENDRV/low)
  - Enter the RESET state when the WD_FAIL_CNT[2:0] reaches a count of 7 and the WD_RST_EN[3] bit is set to 1 (in the SAFETY_FUNC_CFG register; the default state of this bit is 0)

TPS65381-Q1
Application and Implementation
127
Submit Documentation Feedback
Product Folder Links: TPS65381-Q1

Not Recommended for New Designs
Figure 6-12. Software Flowchart for Configuring and Synchronizing the MCU With the Watchdog in Trigger Mode
7 Power Supply Recommendations

The TPS65381-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_SAFEING. The VBATP pin is the main supply pin for the device. The VBAT_SAFEING supply pin is for monitoring (VMON) and BG2 functions. Both the VBATP and VBAT_SAFEING supplies must be reverse protected. The VBAT_SAFEING 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. TPS65381-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:

\[ P_{\text{VDD6}} = (1 - \text{eff}_{\text{VDD6}}) \times 6 \text{ V} \times I_{\text{VDD6}} \]

where

- \( P_{\text{VDD6}} \) 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.
- \( \text{eff}_{\text{VDD6}} \) is the efficiency of VDD6 buck preregulator according to Figure 8-2.
- \( I_{\text{VDD6}} \) is the total load current from VDD5, VDD3/5, VDD1, VSOUT1 and any external load connected to VDD6.

\[ P_{\text{VDD5}} = (6 \text{ V} - 5 \text{ V}) \times I_{\text{VDD5}} = 1 \text{ V} \times I_{\text{VDD5}} \]

where

- \( I_{\text{VDD5}} \) is the load current on VDD5.

\[ P_{\text{VDD3/5}} = (6 \text{ V} - V_{\text{VDD3/5}}) \times I_{\text{VDD3/5}} \]

where

- \( V_{\text{VDD3/5}} \) is either 3.3 V or 5 V.
- \( I_{\text{VDD3/5}} \) is the load current on VDD3/5.

\[ P_{\text{VSOUT1}} = (V_{\text{VSIN}} - V_{\text{VSOUT1}}) \times I_{\text{VSOUT1}} \]

where

- \( V_{\text{VSIN}} \) is either 6 V (VDD6) or VBATP.
- \( V_{\text{VSOUT1}} \) is the programmed output voltage of VSOUT1.
- \( I_{\text{VSOUT1}} \) is the load current on VSOUT1.

\[ P_{\text{TOT}} = P_{\text{VDD6}} + P_{\text{VDD5}} + P_{\text{VDD3/5}} + P_{\text{VSOUT1}} \]

where

- \( P_{\text{TOT}} \) is the total power dissipation in the device.

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.

**Figure 8-2. Typical VDD6 BUCK Efficiency**
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 $R_{\text{thJC}}$. 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 $R_{\text{thJA}}$ as specified in Section 4.4.

![Thermal Derating Profile](image)

A. 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 ($T_{\text{Amax}}$) is dependent on the maximum-operating junction temperature ($T_{\text{Jmax}}$), the maximum power dissipation of the device in the application ($P_{\text{Dmax}}$), and the junction-to-ambient thermal resistance of the part/package in the application ($R_{\text{thJA}}$), as given by the following equation: $T_{\text{Amax}} = T_{\text{Jmax}} - (R_{\text{thJA}} \times P_{\text{Dmax}})$.

B. Maximum power dissipation is a function of $T_{\text{Jmax}}$, $R_{\text{thJA}}$, and $T_{\text{A}}$. The maximum-allowable power dissipation at any allowable ambient temperature is $P_{\text{D}} = (T_{\text{Jmax}} - T_{\text{A}}) / R_{\text{thJA}}$.

**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 in the WEBENCH® Design Center thermal analysis section.

9 Device and Documentation Support

9.1 Device Support

9.1.1 Third-Party Products Disclaimer

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9.2 Documentation Support

9.2.1 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

9.3 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.

9.4 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, 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.

9.5 Trademarks

Hercules, C2000, PowerPAD, E2E are trademarks of Texas Instruments. All other trademarks are the property of their respective owners.
9.6 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.

9.7 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

<table>
<thead>
<tr>
<th>Orderable Device</th>
<th>Status</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>PIns</th>
<th>Package Qty</th>
<th>Eco Plan</th>
<th>Lead/Ball Finish</th>
<th>MSL Peak Temp</th>
<th>Op Temp (°C)</th>
<th>Device Marking</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS65381QDAPRQ1</td>
<td>NRND</td>
<td>HTSSOP</td>
<td>DAP</td>
<td>32</td>
<td>2000</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>NIPDAU</td>
<td>Level-3-260C-168 HR</td>
<td>-40 to 125</td>
<td></td>
<td>TPS65381</td>
</tr>
</tbody>
</table>

(1) The marketing status values are defined as follows:
- **ACTIVE**: Product device recommended for new designs.
- **LIFEBUY**: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
- **NRND**: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
- **PREVIEW**: Device has been announced but is not in production. Samples may or may not be available.
- **OBSOLETE**: TI has discontinued the production of the device.

(2) RoHS: TI defines “RoHS” to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, “RoHS” products are suitable for use in specified lead-free processes. TI may reference these types of products as “Pb-Free”.
- **RoHS Exempt**: TI defines “RoHS Exempt” to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
- **Green**: TI defines “Green” to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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TAPE AND REEL INFORMATION

**DEVICE AND PACKAGE INFORMATION**

<table>
<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>SPQ</th>
<th>Reel Diameter (mm)</th>
<th>Reel Width W1 (mm)</th>
<th>A0 (mm)</th>
<th>B0 (mm)</th>
<th>K0  (mm)</th>
<th>P1  (mm)</th>
<th>W  (mm)</th>
<th>Pin1 Quadrant</th>
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</thead>
<tbody>
<tr>
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<td>HTSSOP</td>
<td>DAP</td>
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<td>2000</td>
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<td>24.4</td>
<td>8.6</td>
<td>11.5</td>
<td>1.6</td>
<td>12.0</td>
<td>24.0</td>
<td>Q1</td>
</tr>
</tbody>
</table>

*All dimensions are nominal.*

**TAPE DIMENSIONS**

- A0: Dimension designed to accommodate the component width
- B0: Dimension designed to accommodate the component length
- K0: Dimension designed to accommodate the component thickness
- W: Overall width of the carrier tape
- P1: Pitch between successive cavity centers

**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**

- Pocket Quadrants
- Sprocket Holes
- User Direction of Feed

*www.ti.com 29-Sep-2019*
## TAPE AND REEL BOX DIMENSIONS

*All dimensions are nominal*

<table>
<thead>
<tr>
<th>Device</th>
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<th>SPQ</th>
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<th>Width (mm)</th>
<th>Height (mm)</th>
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<td>2000</td>
<td>350.0</td>
<td>350.0</td>
<td>43.0</td>
</tr>
</tbody>
</table>
This image is a representation of the package family, actual package may vary. Refer to the product data sheet for package details.
NOTES:

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.

PowerPAD is a trademark of Texas Instruments.
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) and SLMA004 (www.ti.com/lit/slma004).
9. Size of metal pad may vary due to creepage requirement.
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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