Design Guide: TIDA-020111

2-Wheeler Anti-Lock Braking System (2W ABS) Reference Design

Description

Anti-lock braking systems (ABS) are critical safety components in 2-wheeler vehicles, gaining significant prominence to enhance safety-critical braking performance. This reference design provides a comprehensive, functional 2-wheeler ABS design that balances cost-effectiveness with high performance. The hardware, software, and functional safety (FuSa) concept are all illustrated in this guide. This reference design can also be referred to as 1-wheeler ABS or for even lower-cost version based on customers' performance and FuSa requirement.

Features

- 1-wheeler/2-wheeler ABS-compatible design
- 12V ASIL B (Equal to MSIL-C) compatible design
- Flexible discrete components design
- < 100µA standby consumption power
- Typical 2.5A continuous valve current and 10A continuous pump motor current
- 79mm × 46mm × 8mm compact board size

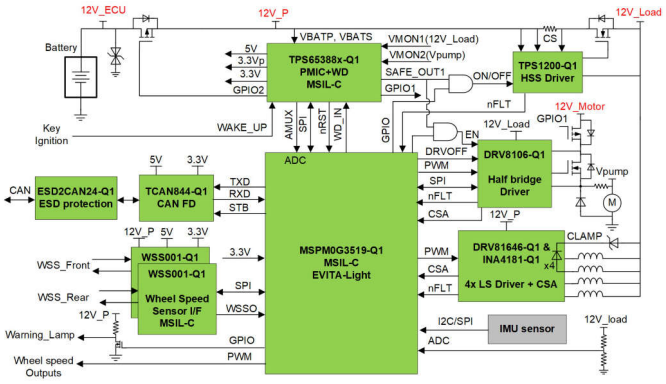
Applications

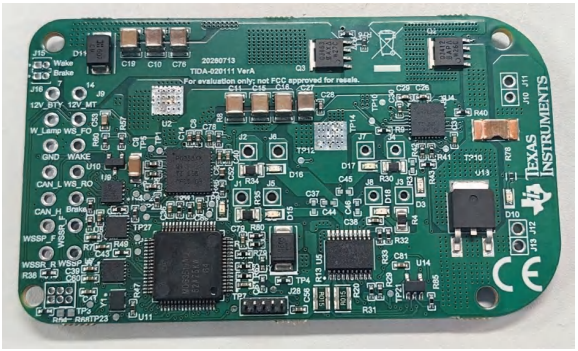
- 2-wheeler anti-lock braking system (ABS)

Resources

TIDA020111, MSPM0-SDK	Design Folder
MSPM0G3519-Q1, TMDSEMU110-U, LP-XDS110	Product Folder
TPS65388x-Q1, TPS65036x-Q1	Product Folder
TCAN844-Q1, INA4181-Q1	Product Folder
TPS1200-Q1, DRV8106-Q1	Product Folder
DRV81646-Q1, DRV81325-Q1	Product Folder

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1 System Description

As two-wheelers move toward electrification and increased intelligence, ABS is gaining significant prominence to enhance safety-critical braking performance. By preventing wheel lock-up and skidding during emergency braking, the system directly enhances rider safety while significantly improving vehicle stability and control during cornering and on varying road surfaces. The TIDA-020111 is a high-performance, cost-optimized ABS reference design from Texas Instruments. This guide details the complete system architecture, including hardware design, software implementation, and FuSa considerations. Furthermore, this design is highly scalable; it can be adapted into a 1-wheeler ABS or a reduced-cost version to meet specific customer performance and FuSa requirements.

1.1 Terminology

ABS	Anti-lock braking systems
FuSa	Functional safety
MCU	Microcontroller
CAN	Controller area network
MOSFET	Metal oxide semiconductor field effect transistor
PMIC	Power management integrated circuit
EMI	Electromagnetic interference
IMU	Inertial measurement unit
FSR	Functional safety requirement
FMEA	Failure mode and effects analysis
FTTI	Fault tolerant time interval
MPFHTI	Maximum probabilistic fault handling time interval
SM	Safety mechanism
HSS	High-side switch
NVM	Non-volatile memory

1.2 Key System Specifications

The TIDA-020111 specifications are listed in Table 1-1.

Table 1-1. Key System Specifications

PARAMETER	SPECIFICATION (UNITS)	NOTES
Input Voltage (12V_ECU)	8V – 20V. 12V (Typ.)	
Motor Voltage (12V_Motor)	8V – 20V. 12V (Typ.)	Short to 12V_ECU on the board if no need to split them.
Valve Current (I_Valve, Each channel)	2.2A (Typ.)	Related to the valve spec and input voltage
Pump Motor Current (I_Motor)	2.5A (Typ. Without Hydraulic) 10A (Typ. With Hydraulic)	Related to the motor spec, load damping and input voltage.
12V_ECU and 12V_Motor OV/UV Protection	32V OV, 6V UV.	
Valve OC/SC Protection (Each channel)	3A OC, 4A SC	
Pump Motor OC/SC Protection	25A OC, 35A SC	
Standby Current	< 100uA	Wake-up by PMIC
Board Size	79mm × 46mm × 8mm	

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WARNING

TI intends this reference design to be operated in a lab environment only and does not consider the device to be a finished product for general consumer use.

TI intends this reference design to be used only by qualified engineers and technicians familiar with risks associated with handling high-voltage electrical and mechanical components, systems, and subsystems.

Hot surface! Contact can cause burns. **Do not touch!** Some components can reach high temperatures >55℃ when the board is powered on. The user must not touch the board at any point during operation or immediately after operating, as high temperatures can be present.

CAUTION

Do not leave te design powered when unattended.

WARNING

External Connections: All external connections to the hardware must stay within the recommended operating condition sand intended usage for all hardware/components connected in the system.

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2 System Overview

2.1 Block Diagram

Figure 2-1 shows the system architecture and functional block diagram for this reference design.

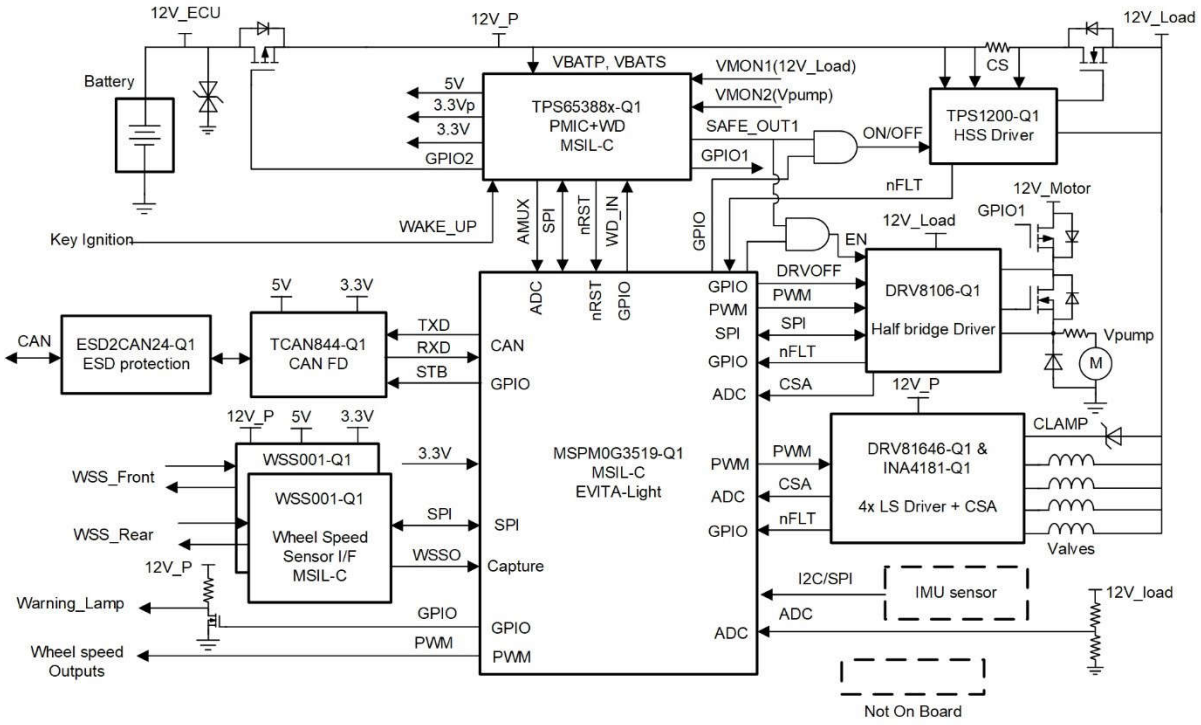


Figure 2-1. TIDA-020111 2W ABS Block Diagram

2.2 Design Considerations

This reference design demonstrates a complete 2-wheeler ABS system implementation, including power tree, microcontroller (MCU), valve and motor drive, sensing, wheel speed sensor interface, controller area network (CAN) transceivers, and FuSa consideration design. All relevant hardware design files are available for download on ti.com.

2.3 Highlighted Products

The following products are central to this reference design. The selection criteria and key technical features for these devices are detailed in the subsequent sections of this guide. For comprehensive specifications, please refer to the individual product datasheets.

2.3.1 MSPM0G351x-Q1

MSPM0G351x-Q1 MCUs are part of the MSP highly integrated, ultra-low-power 32-bit MCU family based on the enhanced Arm® Cortex®-M0+ 32-bit core platform, operating at up to 80MHz frequency. These MCUs offer a blend of cost optimization and design flexibility for applications requiring 256KB to 512KB of flash memory in small packages or high pin count packages (up to 100 pins). These devices include dual CAN-FD controllers, cybersecurity enablers, high performance integrated analog, and provide excellent low power performance across the operating temperature range.

The device has up to 512KB of embedded flash program memory with built-in error correction code (ECC) and up to 128KB SRAM (with ECC and parity protection for the first 64kB). The flash memory is organized into two main banks to support field firmware updates, with address swap support provided between the two main banks.

MSPM0G351x-Q1 MCUs are supported by an extensive hardware and software ecosystem with reference designs and code examples to get the design started quickly. Development kits include a LaunchPad available for purchase. TI also provides a free MSPM0 Software Development Kit (SDK), which is available as a

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component of Code Composer Studio™ IDE desktop and cloud version within the TI Resource Explorer. MSPM0 MCUs are also supported by extensive online collateral, training with MSP Academy, and online support through the TI E2E support forums.

For complete module descriptions, see the MSPM0 G-Series 80MHz Microcontrollers Technical Reference Manual.

2.3.2 TPS65388x-Q1

The TPS65388x-Q1 device is a multi-rail power supply designed to supply microcontrollers, sensors, transceivers and peripherals in safety relevant applications. TPS65388x-Q1 has both ASIL D and ASIL B variant versions. Considering the safety goal of the 2-wheeler ABS, ASIL-B FuSa-compliant TPS65388x-Q1 is selected in this reference design.

2.3.3 TPS1200-Q1

The TPS1200-Q1 is a 45V, low-IQ smart high-side driver with protection and diagnostics. With wide operating voltage range of 3.5V to 40V, the device is practical for 12V system designs. The device can withstand and protect the loads from negative supply voltages down to -40V. The TPS1200-Q1 has a strong (2A) gate drive that enables power switching using parallel metal oxide semiconductor field effect transistors (MOSFETs) in high current system designs.

The device provides adjustable short circuit protection. Auto-retry and latch-off fault behavior can be configured. By using CS+ and CS– pins, current sensing can be done either by an external sense resistor or by MOSFET VDS sensing. High-side or low-side current sense resistor configuration is possible by using CS_SEL pin input. The device also features diagnosis of the internal short circuit comparator using external control on SCP_TEST input. Low quiescent current 43µA (typical) in operation enables always ON system designs. Quiescent current reduces to 1.5µA (typical) with EN/UVLO low.

2.3.4 DRV8106-Q1

The DRV8106-Q1 is a highly integrated half-bridge gate driver, capable of driving high-side and low side N-channel power MOSFETs. The device generates the proper gate drive voltages using an integrated doubler charge pump for the high side and a linear regulator for the low side.

The device uses a smart gate drive architecture to reduce system cost and improve reliability. The gate driver optimizes dead time to avoid shoot-through conditions, provides control to decreasing electromagnetic interference (EMI) through adjustable gate drive current, and protects against drain to source and gate short conditions with VDS and VGS monitors.

A wide common mode shunt amplifier provides inline current sensing to continuously measure motor current even during recirculating windows. The amplifier can be used in low-side or high-side sense configurations if inline sensing is not required.

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2.3.5 DRV81646-Q1

The DRV81646-Q1 is a four-channel low-side switch driver that operates from 4.5V to 65V and supports a wide range of load currents. The device integrates four low-side switches with an RDS (ON) of 140mΩ, each with a freewheeling diode to the VCLAMP pin. This feature allows the user to either recirculate current or connect an external TVS for inductive load turn-off.

The device can be controlled through a hardware GPIO interface or standard 4-wire SPI. Each channel features individual overtemperature protection, and an analog current limit adjustable with an external resistor on the ILIM pin. There is an optional cut-off delay (COD) configuration which limits the duration of a current-limiting condition on the respective channel, helping to prevent damage to the device or the load. The output slew rates are configurable by setting a resistor on the RSLEW/CNTL pin, providing further flexibility in the control of the output switches. The device has an INRUSH mode boosting the current limit threshold for capacitive loads.

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The DRV81646-Q1 provides a fault output pin to indicate fault conditions, and per-channel fault status can be monitored in SPI mode. This feature allows the user to quickly identify and respond to any faults that occur.

2.3.6 DRV81325-Q1

The DRV81325/A -Q1 integrates two protected low side switches with a low RDS(ON) of 110mΩ. The device can be controlled by means of a GPIO interface. Each channel is protected against over current by means of an internal fixed threshold current limit. Channels are protected against overtemperature by integrated overtemperature sensor. Each channel has integrated output overvoltage protection for inductive load demagnetization. The protection features of each individual channel work independent of other channel. Fault report are available per each channel as an open drain STATUS output (A variant). The DRV81325/A-Q1 is available in 8-pin SOIC(D) package and 8-pin HSOIC(DDA) thermally enhanced package

2.3.7 TCAN844-Q1

The TCAN844-Q1 is a high-speed controller area network (CAN) transceiver that is compatible with physical layer requirements of the ISO 11898-2:2024 high-speed CAN specification. The device includes internal logic level translation through the VIO pin to allow for interfacing the transceiver I/O directly to 3.3V, or 5V logic levels. The transceiver supports a low-power standby mode and wake over CAN which is compatible to the ISO 11898-2:2024 defined wake-up pattern (WUP).

The transceivers also include thermal-shutdown (TSD), TXD-dominant time-out (DTO), supply undervoltage detection, and ±40V bus fault protection. The devices have defined fail-safe behavior in supply undervoltage or floating pin scenarios. These transceivers are not only available in industry standard SOIC-8 and VSON-8 packages, but also have a space-saving small footprint SOT-23 package option.

2.3.8 WSS001-Q1

The WSS001-Q1 device is a single channel wheel-speed sensor interface chip designed for use in harsh automotive environments requiring few external components. There is configurable wheel-speed sense input capable of handling active sensors. WSS001-Q1 supports five decoding modes to decode 2-Level, 3-Level AK protocol and 3-Level high-resolution AK protocol sensor. WSS001-Q1 outputs the sensor speed signal from WSSO output for MCU to measure the wheel speed and sensor signal decoded result is stored in internal register bits that can be accessed through SPI.

The WSS001 device uses 32-bit SPI protocol for communication. I/O pins accept 5V and 3.3V supply.

Please contact the local TI sales representative for more detailed WSS001-Q1 information.

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3 System Design Theory

This reference design is intended for both 1-wheeler and 2-wheeler ABS applications.

3.1 Power Tree Design

The power tree is managed by the power management integrated circuit (PMIC) TPS65388x-Q1, which handles reverse polarity protection, power rail generation, wake-up sequencing, and key power rail monitoring, as illustrated in Figure 3-1.

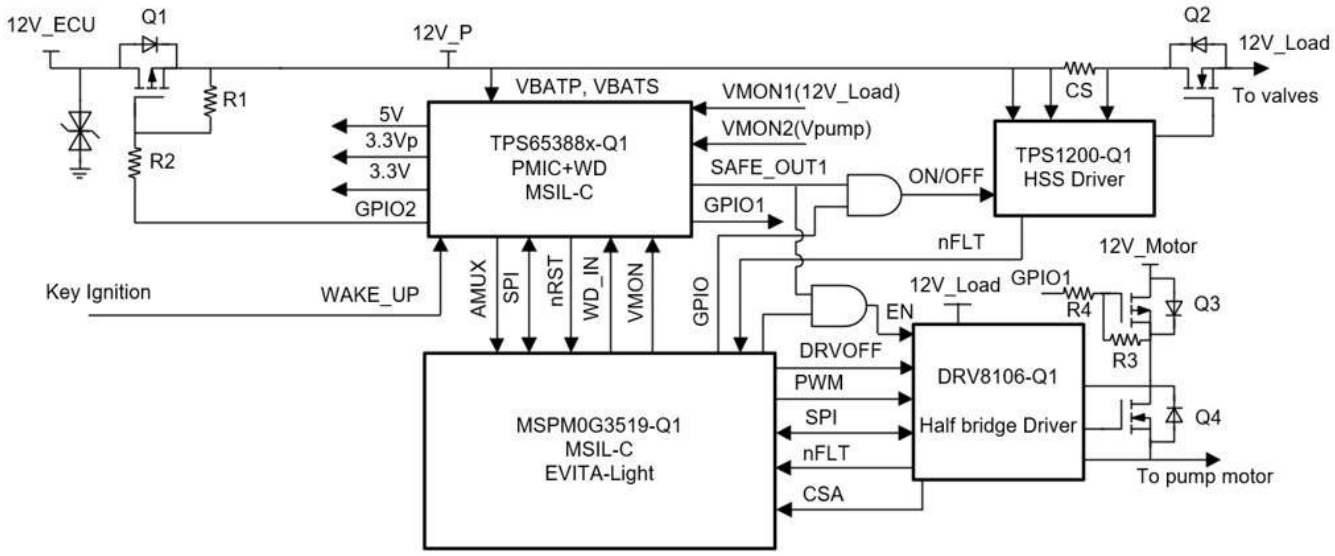


Figure 3-1. Power Tree Design

3.1.1 Input Power

To provide design flexibility, the battery voltage is split into two independent inputs: 12V_ECU and 12V_Motor.

- **12V_ECU** powers the PMIC, MCU, sensors, CAN transceivers, and solenoid valves.
- **12V_Motor** specifically powers the pump motor through the DRV8106-Q1.

This dual-input architecture allows engineers to implement independent protection (such as separate e-fuses) for different loads at the vehicle level. If separate protection is not required, 12V_ECU and 12V_Motor can be shorted together on the ABS board.

3.1.2 Reverse Polarity Protection and Wake-Up

Reverse polarity protection is implemented using two P-MOSFETs (Q1 and Q3) connected directly to the input rails. These are controlled by the high-voltage GPIOs of the TPS65388x-Q1.

- **During a reverse polarity event:** Q1 and Q3 block the current because there is no valid Vgs to turn them on.
- **During normal operation (Pre-Wake-up):** The body diodes of Q1 and Q3 conduct, providing a valid power rail to the system. Because the PMIC is in OFF state, GPIO1 and GPIO2 are Hi-Z. Via R1 and R3, the two P-MOSFETs, keep turning off.
- **Post-Wake-up:** Once the TPS65388x-Q1 receives a valid wake-up signal (for example, KL15 signal), the device drives GPIO1 and GPIO2 low (per non-volatile memory (NVM) configuration) to turn on Q1 and Q3. This transition from body-diode conduction to MOSFET conduction significantly reduces power dissipation and heat. Following this, the TPS65388x-Q1 transitions from OFF or STANDBY into the INIT or PWRU_SEQ states.

3.1.3 On-Board Power Rails and PMIC Schematic Design

Upon successful wake-up, the TPS65388x-Q1 internal buck converters activate the 5V and 3.3V LDOs:

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- **3.3V Rail:** Powers the MSPM0G351x-Q1 MCU, provides the required I/O voltage levels, and serves as the ADC reference voltage.
- **3.3VP Rail:** Reserved for connecting to external sensors which features protection for short-to-battery and short-to-ground.
- **5V Rail:** Powers the TCAN844-Q1 transceiver and the WSS001-Q1 wheel speed sensor interface.
- **12V_Load:** Controlled by the TPS1200-Q1 (via Q2), this rail provides regulated power to the valves and the DRV8106-Q1.

Additionally, a protected 3.3Vp rail is provided to power external devices with the protection of short-circuit. The schematic design for TPS65388x-Q1 is shown in Figure 3-2.

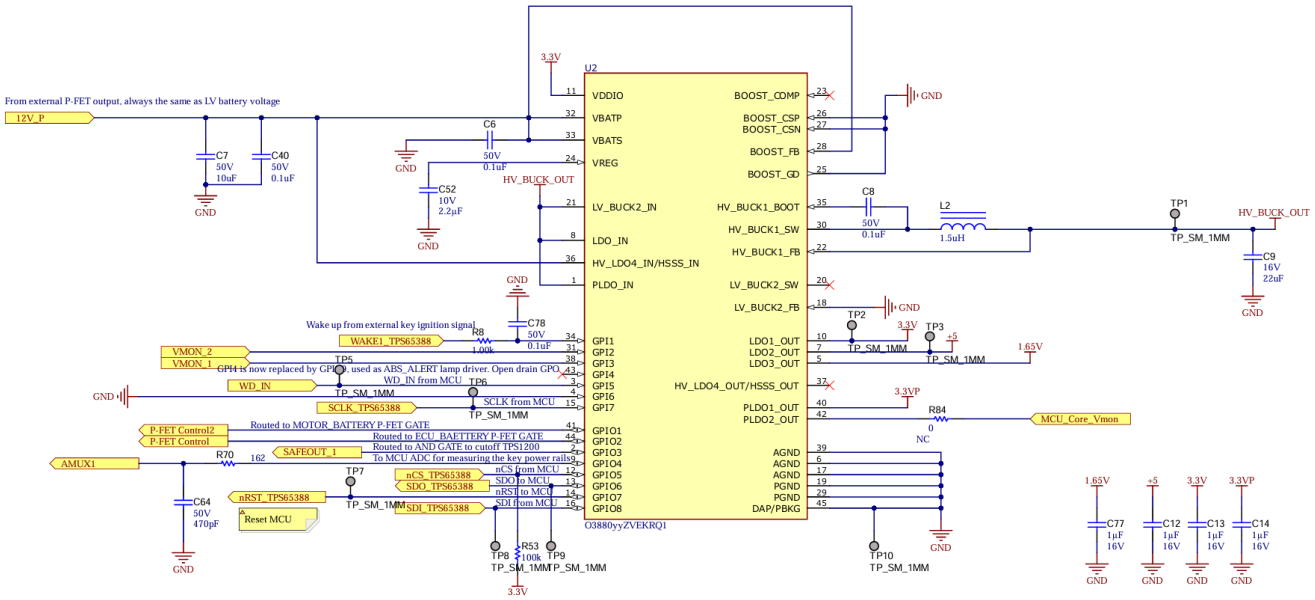


Figure 3-2. PMIC Design

- **GPIO and Pin Configuration:** Table 3-1 summarizes the pin assignments for the TPS65388x-Q1 in this design:

Table 3-1. TPS65388x-Q1 Pin Assignment.

Pin	Assignment	Function/Description
GPI1	WAKE1	External wake-up signal input (for example, KL15)
GPI2	VMON_2	Monitors the pump motor high-side voltage for FuSa monitoring.
GPI3	VMON_1	Monitors the TPS1200-Q1 output voltage for FuSa monitoring.
GPI5	Watchdog	Input for the MCU watchdog timer.
GPI6	Not used, connect to GND	-
GPI7	SPI SCLK	SPI Clock input.
GPIO1	12V_ECU Control	Controls the 12V_ECU reverse polarity protection P-MOSFET.
GPIO2	12V_Motor Control	Controls the 12V_Motor reverse polarity protection P-MOSFET.
GPIO3	SAFEOUT_1	Safety output to disconnect all loads in the event of an MCU failure.
GPIO4	AMUX1	Analog mux for reporting PMIC rail voltages and die temperature.
GPIO5	SPI nCS	SPI Chip selection input pin.
GPIO6	SPI SDO	SPI Data output.
GPIO7	nRST	MCU reset control pin.
GPIO8	SPI SDI	SPI Data input.
GPIO9	Not used, left floating	-
PLDO2_OUT	VMON_ext	Configured to detect MCU core voltage Overvoltage/Undervoltage (OV/UV) for FuSa design.

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3.2 Load Driver Design

The system controls four solenoid valves and one brushed DC pump motor using the DRV81646-Q1 and DRV8106-Q1, respectively, as shown in Figure 3-3.

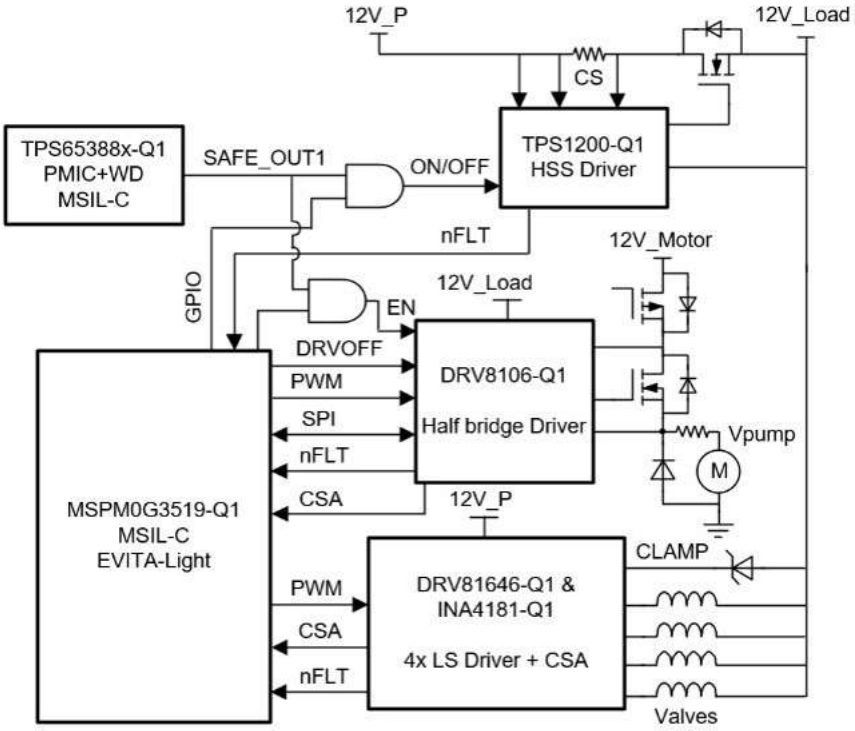


Figure 3-3. Load Driver Design

3.2.1 DRV8106-Q1 Design for Pump Motor Drive

The DRV8106-Q1 family of devices support two different interface modes (SPI and hardware) to allow the end application to design for either flexibility or simplicity. In this reference design, the SPI configuration mode driver is selected to drive a high-side switch (HSS) to control the pump motor. The schematic design for this implementation is shown Figure 3-4.

To meet FuSa requirement, the DRVOFF and Pump_HiZ pins are controlled by both the MCU (via GPIO) and the PMIC (via SAFE_OUT) to enable or disable the output during a fault. SPI configuration allows for fine-tuning of fault report, overcurrent protection, gate driving strength, driving slew rate, current sensing amplifier gain, and so forth.

Additionally, a TMP61-Q1 temperature sensor is placed near the driver MOSFETs to provide over-temperature protection.

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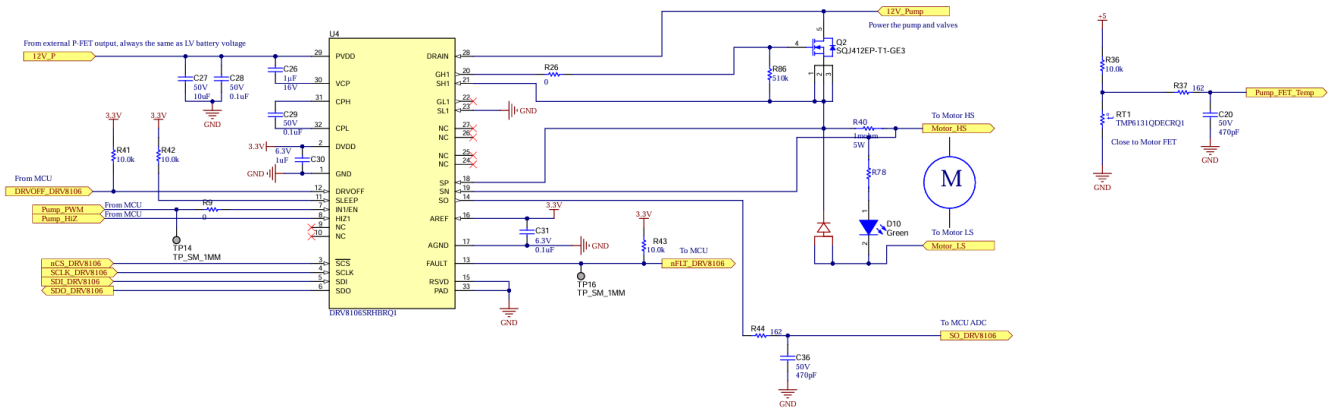


Figure 3-4. DRV8106S-Q1 Design

3.2.2 TPS1200-Q1 Design for Load Cut-Off

The TPS1200-Q1 HSS driver is utilized as a primary safety cut-off for the solenoid valve driving path and the DRV8106-Q1 power supply. In the event of a system failure, both the MCU and the PMIC (SAFE_OUT) can trigger the TPS1200-Q1 to disconnect the loads. The schematic is shown in Figure 3-5. A 3mΩ shunt resistor is connected in series with the MOSFET for TPS1200-Q1 short circuit protection (optional current sensor for MCU measuring the current). Key parameters, including input OV/UV thresholds, short-circuit current thresholds, gate driving strength, and slew rate, are configurable through external resistors and capacitors.

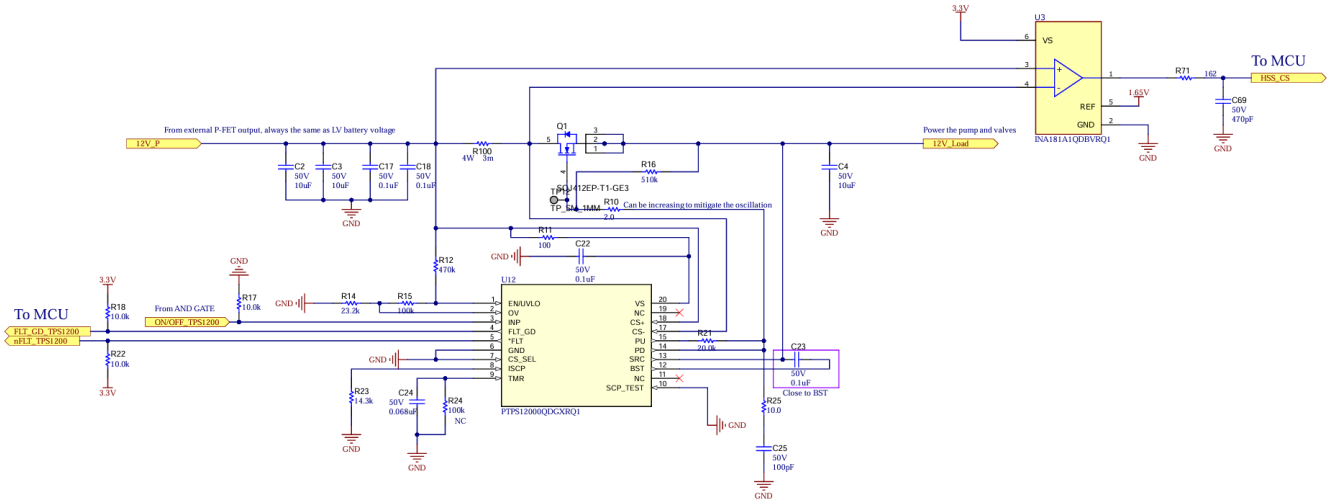


Figure 3-5. TPS1200-Q1 Design

3.2.3 DRV81646-Q1 Design for Valve Drive

The DRV81646-Q1 integrates four low-side switch channels, featuring integrated overcurrent limitation and overtemperature protection. This allows for independent control of four solenoid valves.

Since the DRV81646-Q1 does not include integrated current-sensing amplifiers, this design utilizes an INA4181-Q1 (a 4-channel amplifier with integrated resistors and selectable gain) to monitor valve currents. The FET DC current capability per channel (PWP package) is detailed in Table 3-2.

Table 3-2. DRV81646-Q1 FET DC Current Capability per OUTx – PWP Package

Setup	25℃	55℃	85℃	125℃
1 Channel on	3.7A	3.4A	3.2A	2.5A
2 Channels on	3.5A	3.0A	2.7A	2.1A
4 Channels on	2.7A	2.4A	2.0A	1.5A

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To protect against voltage transients for fast cutoff, a 24V TVS diode is connected between the VCLAMP pins and the 12V_Load. A 100kΩ resistor is placed in parallel with the TVS to discharge any residual charge. For testing purposes, four pairs of LEDs/diodes are included to indicate valve status; these can be removed in the final production design. For current measurement, 0.015mΩ shunt resistors are placed on the valve low-sides, with the INA4181-Q1 performing the sensing. The schematic is shown in Figure 3-6.

Note

For 1-wheeler ABS applications, the DRV81325-Q1 (2-channel low-side switch) can be used as a replacement.

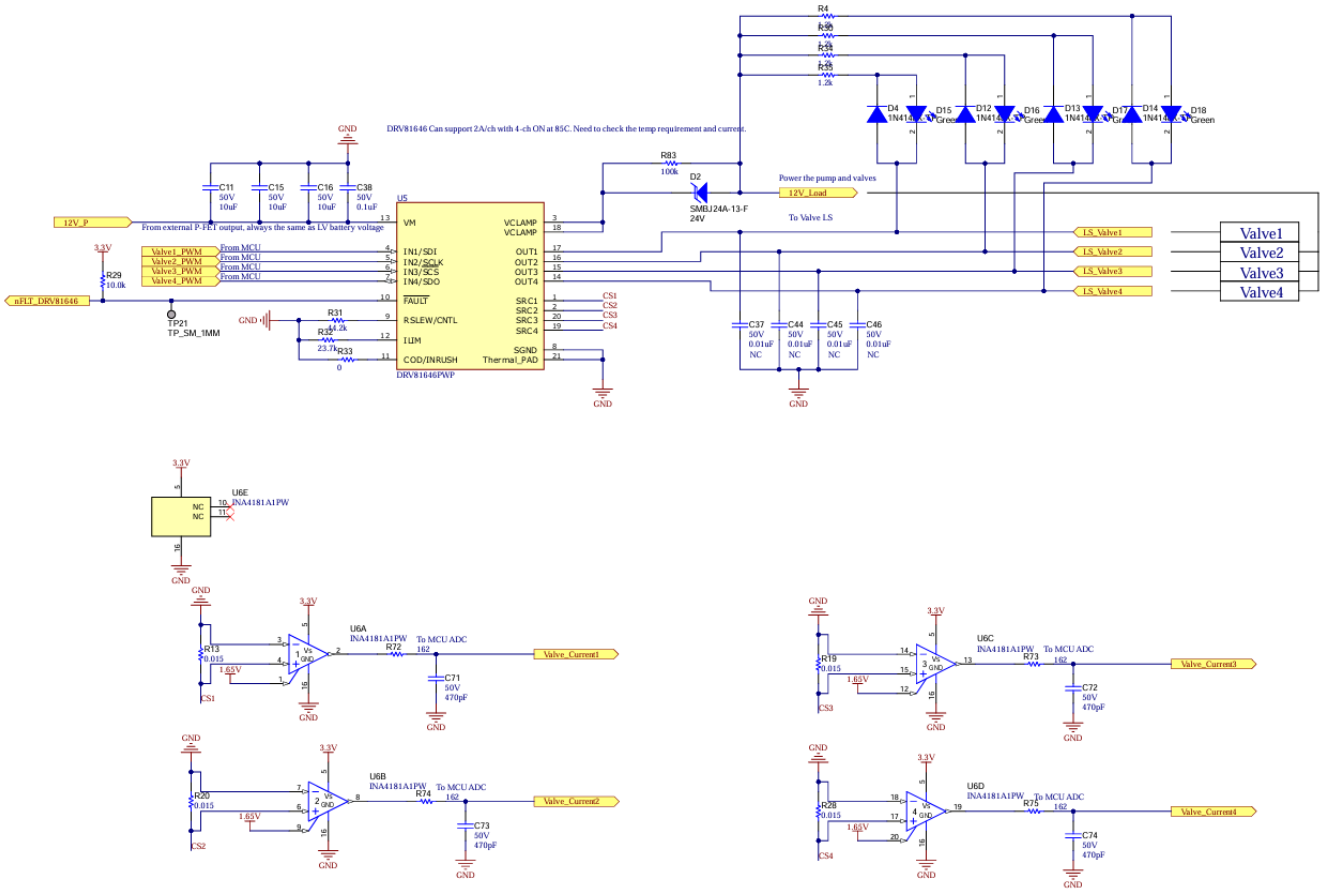


Figure 3-6. DRV81646-Q1 Design

3.3 Sensing and Communication Design

To execute the ABS control strategy, the system requires commands from the vehicle side, inputs from wheel speed sensors and an Inertial Measurement Unit (IMU), as well as the current feedback from the valves and the pump motor for actuation and protection.

In this reference design:

- **Wheel Speed Decoding Signals:** Two WSS001-Q1 provide the required wheel speed decoding signals.
- **Current Sensing:** Valve currents are monitored via the INA4181-Q1 4-channel current sensing amplifier. For the pump motor, the DRV8106-Q1's integrated current-sensing amplifier is used, eliminating the need for an external sensor.
- **Communication:** CAN FD communication is provided by the TCAN844-Q1 to interface with external vehicle networks. This design supports two ABS actuation trigger modes: external CAN command triggering and internal MCU algorithm triggering. TLIN829-Q1 can be used for LIN or K-LINE communication if needed.
- **Protection:** The ESD2CAN24-Q1 is utilized for robust ESD protection on the CAN lines.

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- **IMU:** An IMU is not included in this hardware implementation but can be integrated externally through SPI or I2C interfaces.

The block diagram for the sensing and communication subsystem is shown in Figure 3-7. Detailed schematics for the WSS001-Q1 and TCAN844-Q1 are provided in Figure 3-8 and Figure 3-9, respectively.

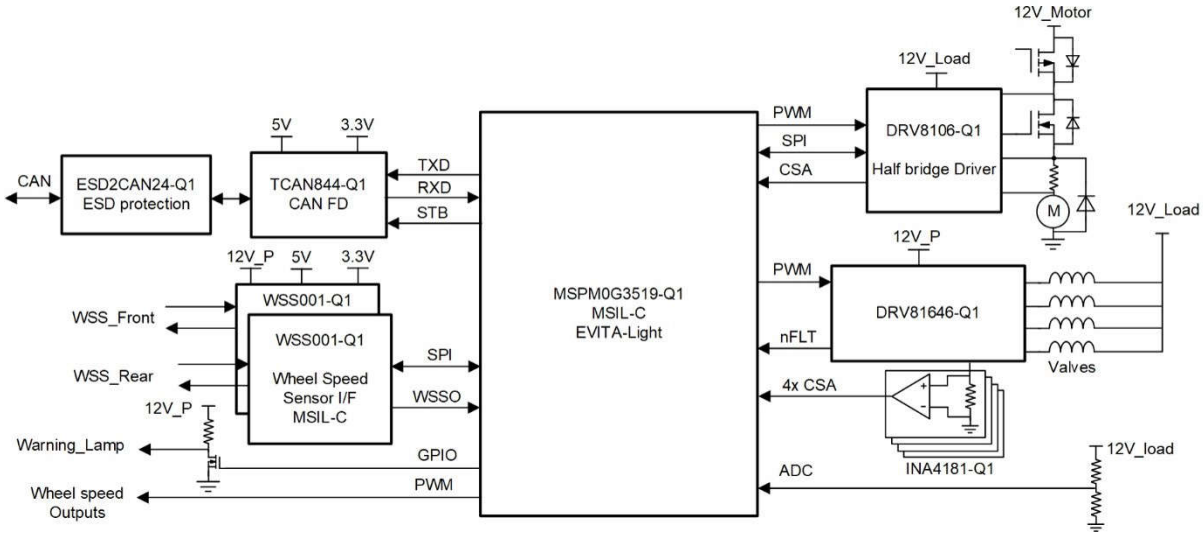


Figure 3-7. Sensing and Communication Design

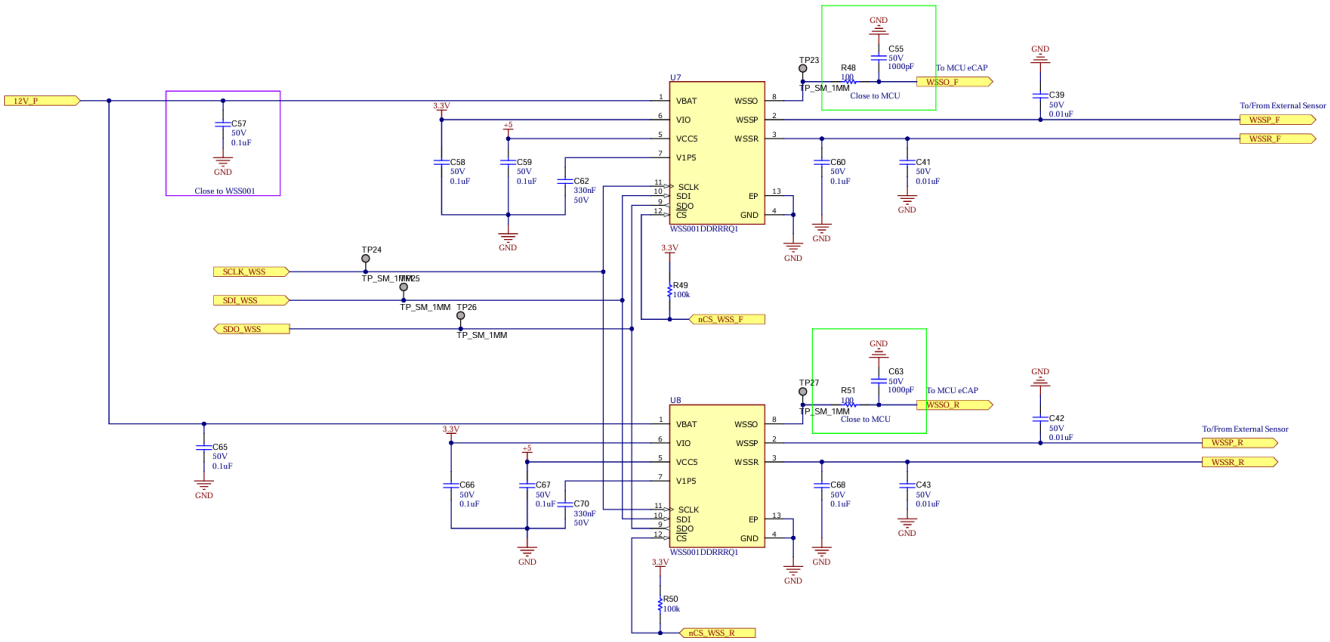


Figure 3-8. WSS001-Q1 Design

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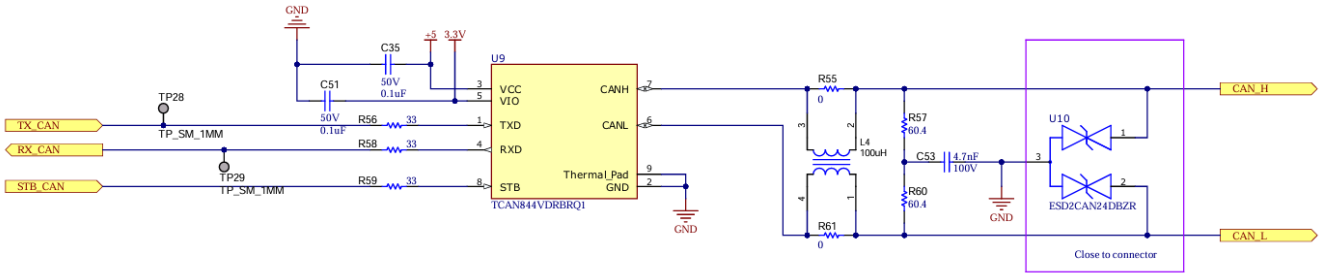


Figure 3-9. TCAN844-Q1 Design

3.4 Processor Schematic Design

The MSPM0G3519-Q1 (64-pin LQFP package) serves as the central digital processor for this reference design, as shown in Figure 3-10. A 20.000MHz external clock is provided by the CDC6C-Q1 oscillator. For detailed implementation guidelines regarding the MSPM0G series, please refer to the MSPM0 G-Series MCUs Hardware Development Guide (Rev. E).

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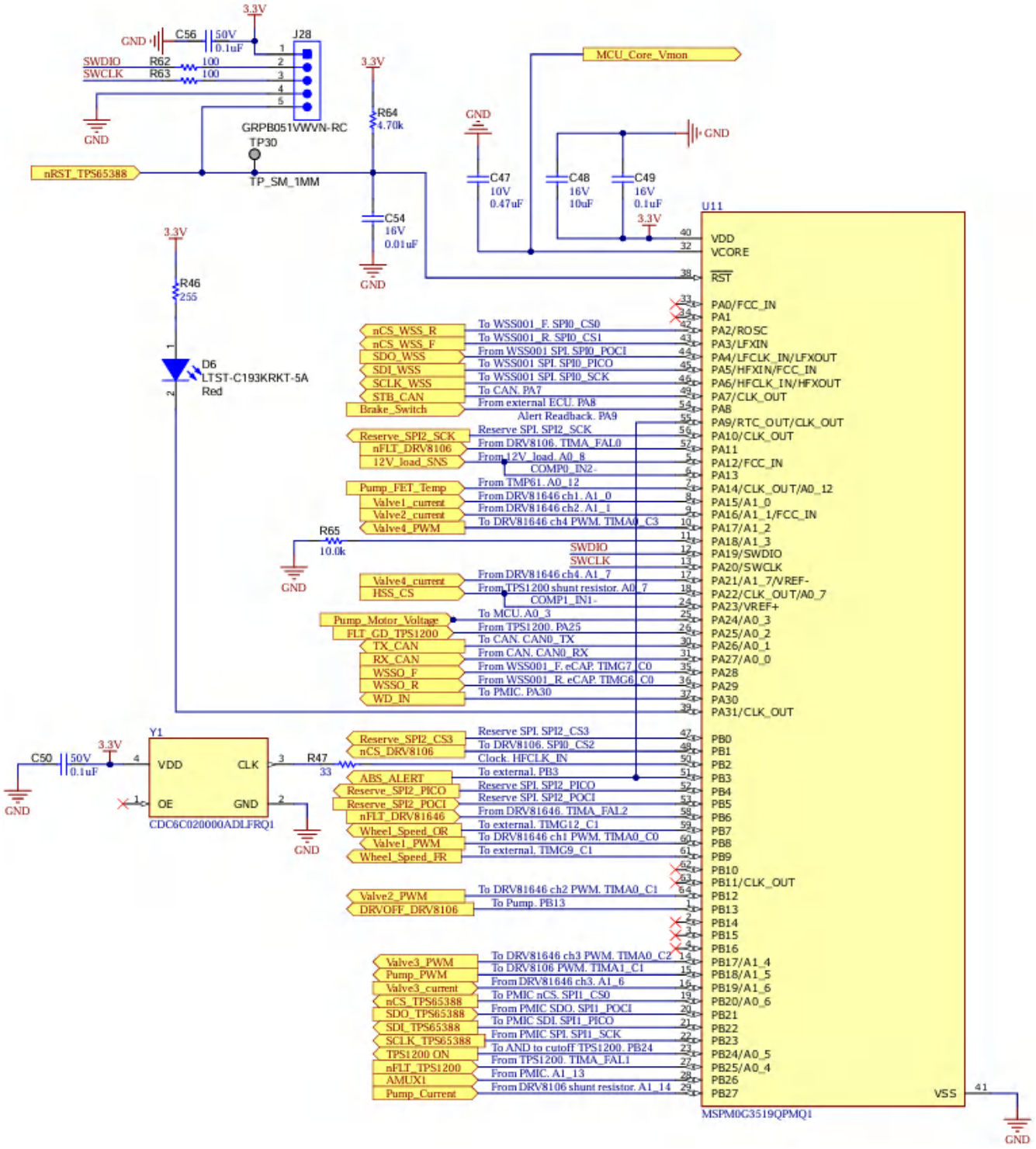


Figure 3-10. MSPM0G3519-Q1 Design

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3.5 Diagnostics Design and FuSa Analysis

This reference design incorporates multiple diagnostic layers to facilitate rapid customization for safety-critical applications. This reference design includes TI products that help comply with applicable ISO 26262 requirements up to **ASIL B (equals to MSIL-C)**, with the primary safety goal of ensuring the immediate disconnection of all solenoid valves and the pump motor in the event of a critical failure.

Table 3-3 shows the FuSa requirement (FSR), and Table 3-4 shows the failure mode and effects analysis (FMEA) to illustrate the key safety mechanisms (SMs) to meet the requirements of the FSR.

Note: The Fault Tolerant Time Interval (FTTI) and Maximum Probabilistic Fault Handling Time Interval (MPFHTI) are implementation-specific and should be determined based on your specific system-level safety requirements.

Table 3-3. FSR of the Reference Design

FSR ID	FSR	Safe State	MSIL level	FTTI
1.1	ABS system shall correctly transfer the ABS actuating command to MCU with the interface circuit.	Report warning to external part. Cutoff all actuators	MSIL-C	FTTI
1.2	ABS system shall correctly perform communication command decode by MCU.	Report warning to external part. Cutoff all actuators	MSIL-C	FTTI
1.3	ABS system shall correctly provide power supply for interface circuit.	Report warning to external part. Cutoff all actuators	MSIL-C	FTTI
1.4	ABS system shall correctly decode the wheel speed signal by wheel speed sensing circuit.	Report warning to external part. Cutoff all actuators	MSIL-C	FTTI
1.5	ABS system shall correctly perform wheel speed sensing output signal decode by MCU.	Report warning to external part. Cutoff all actuators	MSIL-C	FTTI
1.6	ABS system shall correctly provide power supply for wheel speed sensing circuit.	Report warning to external part. Cutoff all actuators	MSIL-C	FTTI
1.7	ABS system shall correctly support control algorithm run in MCU.	Report warning to external part. Cutoff all actuators	MSIL-C	FTTI
1.8	ABS system shall correctly provide the PWM to control valve and motor by MCU	Report warning to external part. Cutoff all actuators	MSIL-C	FTTI
1.9	ABS system shall correctly provide power supply for MCU	Report warning to external part. Cutoff all actuators	MSIL-C	FTTI
1.10	ABS system shall correctly amplify the PWM signal into driving signal in valve driver circuit	Report warning to external part. Cutoff all actuators	MSIL-C	FTTI
1.11	ABS system shall correctly amplify the PWM signal into driving signal in motor driver circuit	Report warning to external part. Cutoff all actuators	MSIL-C	FTTI
1.12	ABS system shall correctly measure the valve currents.	Generate alerts to MCU Report warning to external part.	MSIL-C	MPFHTI

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Table 3-3. FSR of the Reference Design (continued)

FSR ID	FSR	Safe State	MSIL level	FTTI
1.13	ABS system shall correctly measure the pump motor current	Generate alerts to MCU Report warning to external part.	MSIL-C	MPFHTI
1.14	ABS system shall correctly provide power supply for motor driving circuit	Report warning to external part. Cutoff all actuators	MSIL-C	FTTI
1.15	ABS system shall correctly actuate/deactivate the MOSFET.	Report warning to external part. Cutoff all actuators	MSIL-C	FTTI

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Table 3-4. FMEA of the Reference Design

FSR	Failure Mode	Fault Type	Failure Effect	Safety Mechanism (Detection)	Safety Mechanism (Safety-Ready)	Safety Mechanism (Report)
1.1 1.2 1.3	Cannot receive commands within allowed time when requests	SPF	ABS system cannot actuate ABS and read vehicle side status	MCU cannot receive CAN transceiver output within allowed time. (SM6) Vehicle side cannot read CAN signal from ABS within allowed time. (SM5)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Unintended receiving commands when no requests	SPF	ABS system will unintendedly actuate or receive wrong vehicle side status	CAN E2E mechanisms (SM4)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Cannot report status.	MPF	Vehicle side cannot get the status from ABS system	CAN E2E mechanisms (SM4) Vehicle side cannot read CAN signal from ABS within allowed time. (SM5)	NA	Vehicle report communication error
	Unintended reporting status when no requests	SF	NA	CAN E2E mechanisms (SM4)	NA	NA
	MCU decodes the signal and gets the wrong ABS actuation command	SPF	ABS system will unintendedly actuate or unintended deactivate	MCU send the ABS status to vehicle side. CAN E2E mechanisms (SM4)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	PMIC LDO no output	SPF	Interface circuit cannot work	PMIC LDO voltage monitoring. (3.3V, 5V) (SM7)	PMIC LDO output UV/OV and cutoff (SM8) Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	PMIC LDO output out of range.	SPF	Interface circuit cannot work or damaged	PMIC LDO voltage monitoring. (3.3V, 5V) (SM7)	PMIC LDO output UV/OV and cutoff (SM8) Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)

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Table 3-4. FMEA of the Reference Design (continued)

FSR	Failure Mode	Fault Type	Failure Effect	Safety Mechanism (Detection)	Safety Mechanism (Safety-Ready)	Safety Mechanism (Report)
1.4 1.5 1.6	Cannot receive the wheel speed signal.	SPF	ABS system cannot give wheel speed signal feedback to vehicle for ABS actuation command	WSS001 detects wheel speed sensor signal error and decoding error. Sets fault flags to notify wheel speed signal sensing errors to MCU (SM43)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Wheel speed sensor interface outputs wrong wheel speed signal	SPF	ABS system gives wrong wheel speed signal feedback to vehicle for ABS actuation command	WSS001 detects wheel speed sensor signal error and decoding error. Sets fault flags to notify wheel speed signal sensing errors to MCU (SM43)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	MCU decodes the wheel speed signal and gets the wrong wheel speed.	SPF	ABS system gives wrong wheel speed signal feedback to vehicle for ABS actuation command	WSS001 detects wheel speed sensor signal error and decoding error. Sets fault flags to notify wheel speed signal sensing errors to MCU (SM43)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	PMIC LDO no output	SPF	Wheel speed sensing circuit cannot work	PMIC LDO voltage monitoring. (3.3V, 5V) (SM7)	PMIC LDO output UV/OV and cutoff (SM8) Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	PMIC LDO output out of range.	SPF	Wheel speed sensing circuit cannot work or damaged	PMIC LDO voltage monitoring. (3.3V, 5V) (SM7)	PMIC LDO output UV/OV and cutoff (SM8) Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)

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Table 3-4. FMEA of the Reference Design (continued)

FSR	Failure Mode	Fault Type	Failure Effect	Safety Mechanism (Detection)	Safety Mechanism (Safety-Ready)	Safety Mechanism (Report)
1.7	MCU core power fails.	SPF	MCU cannot run the ABS algorithm and protection	1.35V MCU core voltage monitoring (SM10) Vehicle side cannot read CAN signal from ABS within allowed time. (SM5)	Reset MCU (SM9) PMIC SAFE_OUT valve drivers (SM40) PMIC SAFE_OUT motor driver (SM41) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	MCU memory bit or register bit toggles	SPF	MCU cannot run the ABS algorithm and protection, or output a wrong result, or generate wrong PWM command	Memory and register CRC (SM11) On-chip or external Watchdog (SM45)	Reset MCU (SM9) PMIC SAFE_OUT valve drivers (SM40) PMIC SAFE_OUT motor driver (SM41) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	MCU provide incorrect algorithm output.	SPF	MCU output a wrong result and protection, or generate wrong PWM command	On-chip or external Watchdog (SM45) Redundant code running and make comparison (SM46)	Reset MCU (SM9) Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
1.8	MCU PWM stuck high/low	SPF	Valve and pump motor will unintended actuate/deactivate	On-chip or external Watchdog (SM45) Measures valve current (SM12) Measures motor current (SM16)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	MCU output incorrect PWM signal	SPF	Valve and pump motor will unintended actuate/deactivate	On-chip or external Watchdog (SM45) Measures valve current (SM12) Measures motor current (SM16)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	MCU unintended outputs PWM signal	SPF	Valve and pump motor will unintended actuate/deactivate	On-chip or external Watchdog (SM45) Measures valve current (SM12) Measures motor current (SM16)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)

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Table 3-4. FMEA of the Reference Design (continued)

FSR	Failure Mode	Fault Type	Failure Effect	Safety Mechanism (Detection)	Safety Mechanism (Safety-Ready)	Safety Mechanism (Report)
1.9	PMIC LDO no output	SPF	MCU cannot work	PMIC LDO voltage monitoring. (3.3V) (SM7)	PMIC LDO output UV/OV and cutoff (SM8) Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	PMIC LDO output out of range.	SPF	MCU cannot work or damaged	PMIC LDO voltage monitoring. (3.3V) (SM7)	PMIC LDO output UV/OV and cutoff (SM8) Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)

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Table 3-4. FMEA of the Reference Design (continued)

FSR	Failure Mode	Fault Type	Failure Effect	Safety Mechanism (Detection)	Safety Mechanism (Safety-Ready)	Safety Mechanism (Report)
1.10	Valve driving low-side FET cannot turn on	SPF	Valve cannot turn on	Measures valve current (SM12)	Cutoff motor driver (SM3) Turn off valve HSS. (SM13) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Valve driving low-side FET cannot turn off	SPF	Valve will be always ON	Measures valve current (SM12)	Cutoff motor driver (SM3) Turn off valve HSS. (SM13) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Low-side FET doesn't follow the input PWM	SPF	Valve will unintended actuate	Measures valve current (SM12)	Cutoff motor driver (SM3) Turn off valve HSS. (SM13) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Low-side FET overcurrent	SPF	Potentially damage the valve and device	Measures valve current. (SM12) Valve Overtemperature reports to MCU (SM15)	Valve driver overcurrent protection. (SM14) Cutoff valve drivers (SM2) Cutoff motor driver (SM3) Turn off valve HSS. (SM13) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Low-side FET stuck in resistance region	SPF	Potentially damage the device	Valve Overtemperature reports to MCU (SM15)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) Turn off valve HSS. (SM13) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Valve short circuit	SPF	Overcurrent when try to turn on the valve	Measures valve current. (SM12) Valve Overtemperature reports to MCU (SM15)	Valve driver overcurrent protection. (SM14) Cutoff valve drivers (SM2) Cutoff motor driver (SM3) Turn off valve HSS. (SM13) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)

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Table 3-4. FMEA of the Reference Design (continued)

FSR	Failure Mode	Fault Type	Failure Effect	Safety Mechanism (Detection)	Safety Mechanism (Safety-Ready)	Safety Mechanism (Report)
1.11	Motor driver output stuck low	SPF	Pump motor cannot turn on	Measures motor current (SM16)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Motor driver output stuck high	SPF	Pump motor will be always ON	Measures motor current (SM16)	Turn off valve HSS (to trun off motor driver PVDD to disable charge pump) (SM13) Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Motor driver charge pump is too low to fully turn on the MOSFET	SPF	Potentially damage the FET	Motor driver charge pump UVLO (SM17)	Turn off valve HSS (to trun off motor driver PVDD to disable charge pump) (SM13) Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	Motor driver report charge pump UVLO failure with nFLT and SPI (SM18) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Motor driver output doesn't follow the input PWM	SPF	Pump motor will unintended actuate	Measures motor current (SM16)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Motor driver output is floating	SPF	Pump motor will potentially unintended actuate	Measures motor current (SM16)	Cutoff motor driver (Passive discharge VGS of the pump motor FET.) (SM3) Cutoff valve drivers (SM2) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Motor overcurrent or short circuit	SPF	Overcurrent when try to turn on the motor	Measures motor current (SM16)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)

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Table 3-4. FMEA of the Reference Design (continued)

FSR	Failure Mode	Fault Type	Failure Effect	Safety Mechanism (Detection)	Safety Mechanism (Safety-Ready)	Safety Mechanism (Report)
1.12 1.13	Valve current sensor no output	MPF	Cannot provide valve failure detection	Valve HSS current sensing for plausibility check (SM32)	MCU judge if the failure is from current sensor or valve driver. MCU report warning signal to vehicle side. (SM39)	MCU report warning signal to vehicle side with CAN. CAN E2E mechanisms (SM4)
	Valve current sensor outputs wrong signal	MPF	Cannot or unintended provide valve failure detection	Valve HSS current sensing for plausibility check (SM32)	MCU judge if the failure is from current sensor or valve driver. MCU report warning signsal to vehicle side. (SM39)	MCU report warning signal to vehicle side with CAN. CAN E2E mechanisms (SM4)
	Pump motor current sensor no output	MPF	Cannot provide pump motor failure detection	Measures motor high-end voltage for redundancy (SM35)	MCU judge if the failure is from current sensor or valve driver. MCU report warning signal to vehicle side. (SM39)	MCU report warning signal to vehicle side with CAN. CAN E2E mechanisms (SM4)
	Pump motor current sensor outputs wrong signal	MPF	Cannot or unintended provide pump motor failure detection	Measures motor high-end voltage for redundancy (SM35)	MCU judge if the failure is from current sensor or valve driver. MCU report warning signal to vehicle side. (SM39)	MCU report warning signal to vehicle side with CAN. CAN E2E mechanisms (SM4)
1.14	PMIC LDO no output	SPF	Motor driver cannot output	PMIC LDO voltage monitoring. (3.3V) (SM7) Motor driver SPI to report failure. Measures motor current (SM16)	Cutoff motor driver (Passive discharge VGS of the pump motor FET.) (SM3) Cutoff valve drivers (SM2) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO passive drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	PMIC LDO output out of range.	SPF	Motor driver output wrong	PMIC LDO voltage monitoring. (3.3V) (SM7) Motor driver SPI to report failure. Measures motor current (SM16)	Cutoff motor driver (Passive discharge VGS of the pump motor FET.) (SM3) Cutoff valve drivers (SM2) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO passive drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)

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Table 3-4. FMEA of the Reference Design (continued)

FSR	Failure Mode	Fault Type	Failure Effect	Safety Mechanism (Detection)	Safety Mechanism (Safety-Ready)	Safety Mechanism (Report)
1.15	12V_ECU P-MOS open circuit	SPF	ABS system cannot be powered on	Vehicle side cannot read CAN signal from ABS within allowed time. (SM5)	Cutoff motor driver (Passive discharge VGS of the pump motor FET.) (SM3) Cutoff valve drivers (SM2)	Vehicle report communication error and turn on vehicle side ABS warning lamp
	12V_ECU P-MOS gate voltage stuck high	SPF	Potentially damage the P-FET	Gate voltage detection (SM19)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	12V_ECU P-MOS gate voltage stuck low	MPF	Cannot provide reverse polarity protection	Gate voltage detection at power-on stage (SM19)	NA	MCU report warning signal to vehicle side with CAN.
	12V_ECU Overvoltage	SPF	Potentially damage the system	12V_ECU voltage detection and OV protection. (SM20)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	12V_ECU Undervoltage	SPF	Cannot actuate the ABS	12V_ECU voltage detection and UVLO. (SM21) Vehicle side cannot read CAN signal from ABS within allowed time. (SM5)	Shutdown the system. Cutoff valve drivers (SM2) Passively cutoff motor driver (SM3) Passively turn off valve HSS. (SM13) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	Vehicle side cannot read CAN signal from ABS within allowed time. (SM5)

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Table 3-4. FMEA of the Reference Design (continued)

FSR	Failure Mode	Fault Type	Failure Effect	Safety Mechanism (Detection)	Safety Mechanism (Safety-Ready)	Safety Mechanism (Report)
1.15 (Continued)	12V_Motor P-MOS open circuit	SPF	Pump motor cannot turn on	Measures motor current (SM16)	Cutoff valve drivers (SM2) Passively cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	Vehicle side cannot read CAN signal from ABS within allowed time. (SM5)
	12V_Motor P-MOS gate voltage stuck high	SPF	Potentially damage the P-FET	Gate voltage detection (SM19)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	12V_Motor P-MOS gate voltage stuck low	MPF	Cannot provide reverse polarity protection	Gate voltage detection at power-on stage (SM19)	NA	MCU report warning signal to vehicle side with CAN.
	12V_Motor Overvoltage	SPF	Potentially damage the system	12V_Motor voltage detection and OV protection. (SM22)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	12V_Motor Undervoltage	SPF	Cannot actuate the ABS	12V_Motor voltage detection and UVLO. (SM23)	Shutdown the system. Cutoff valve drivers (SM2) Passively cutoff motor driver (SM3) Passively turn off valve HSS. (SM13) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO passive drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)

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Table 3-4. FMEA of the Reference Design (continued)

FSR	Failure Mode	Fault Type	Failure Effect	Safety Mechanism (Detection)	Safety Mechanism (Safety-Ready)	Safety Mechanism (Report)
1.15 (Continued)	Pump motor HSS D-S open circuit	SPF	Pump motor cannot turn on	Motor driver offline open detection (SM24) Measures motor current (SM16)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Pump motor HSS G-S short circuit	SPF	Pump motor cannot turn on	Motor driver charge pump UVLO (SM17) Motor driver VGS fault (SM25) Measures motor current (SM16)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Pump motor HSS D-S short circuit	SPF	Pump motor will be always ON	Motor driver offline short detection (SM26) Motor driver VDS overcurrent detection (SM27) Measures motor current (SM16)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Pump motor HSS G-D-S short circuit	SPF	Pump motor will be always ON	Motor driver offline short detection (SM26) Motor driver VDS overcurrent detection (SM27) Measures motor current (SM16)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Pump motor recirculation diode short circuit	SPF	Overcurrent when try to turn on the motor	Motor driver offline short detection (SM26) Motor driver VDS overcurrent detection (SM27) Measures motor current (SM16)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) Turn off valve HSS. (SM13) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)

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Table 3-4. FMEA of the Reference Design (continued)

FSR	Failure Mode	Fault Type	Failure Effect	Safety Mechanism (Detection)	Safety Mechanism (Safety-Ready)	Safety Mechanism (Report)
1.15 (Continued)	Pump motor overcurrent	SPF	Potentially damage the motor and device	Motor driver VDS overcurrent detection (SM27) Measures motor current (SM16)	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) Turn off valve HSS. (SM13) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Valve HSS D-S open circuit	SPF	ABS system cannot actuate	12V_Load voltage detection (SM28) Valve HSS current sensing	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Valve HSS G-S short circuit	SPF	ABS system cannot actuate	12V_Load voltage detection (SM28) Valve HSS current sensing	Cutoff valve drivers (SM2) Cutoff motor driver (SM3) MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)	MCU GPIO drive ABS_ALERT signal to turn on vehicle side ABS warning lamp (SM1)
	Valve HSS D-S short circuit	MPF	Valve HSS will be always ON, which cannot provide protection	Power-on-test: 12V_Load voltage detection (SM28)	NA	MCU report warning signal to vehicle side with CAN. CAN E2E mechanisms (SM4)
	Valve HSS G-D-S short circuit	MPF	Valve HSS will be always ON, which cannot provide protection	Power-on-test: 12V_Load voltage detection (SM28)	NA	MCU report warning signal to vehicle side with CAN. CAN E2E mechanisms (SM4)

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4 Hardware, Software, Testing Requirements, and Test Results

4.1 Hardware Requirements

Figure 4-1 shows the TIDA-020111 2W ABS evaluation board with the primary functional blocks highlighted for clarity.

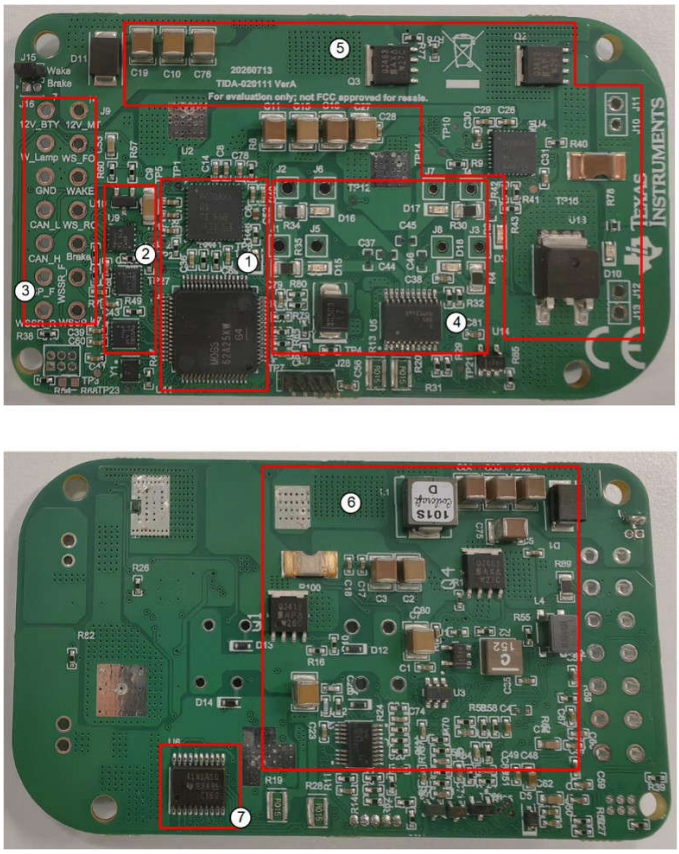


Figure 4-1. Functional Section of TIDA-020111 Board

WARNING

Do not touch any part of the board or components connected to the board when the board is energized.

4.2 Software

To obtain the TIDA-020111 firmware and baseline software packages, please contact your local Texas Instruments sales representative.

4.3 Test Setup

Figure 4-2 shows the TIDA-020111 hardware configuration and connection. The critical functional blocks of this reference design are detailed below:

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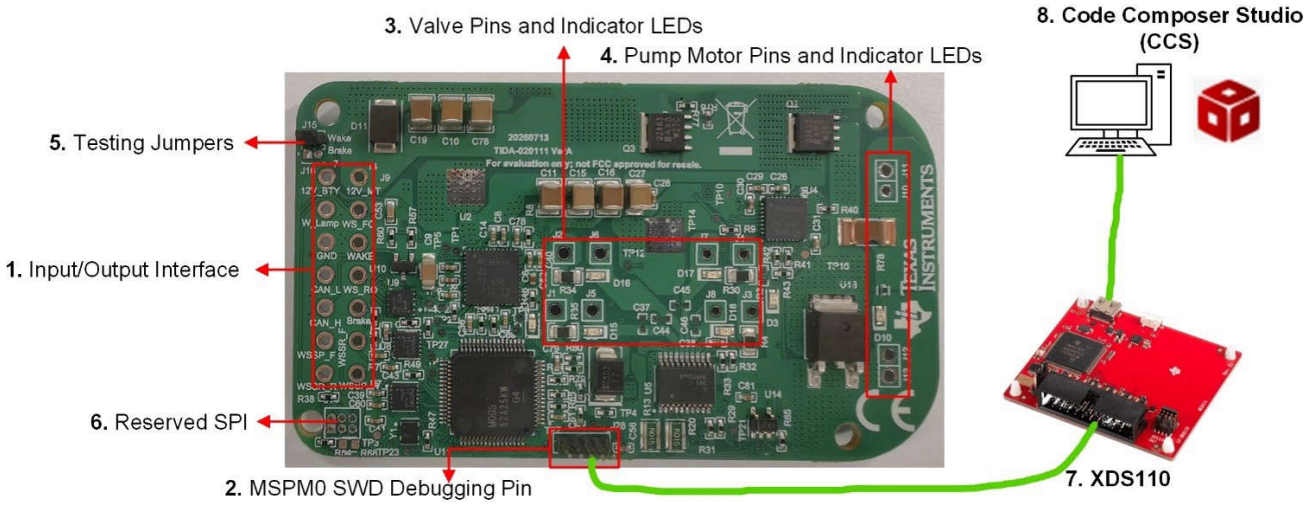


Figure 4-2. TIDA-020111 Setup and Connection

1. **Board Input/Output (I/O) Interface**: The pin definitions for the board interface are provided in Table 4-1.

Table 4-1. Board Input/Output Interface Definition

Pin Number	Pin Name	Pin Description
1	REAR_WS_LO	Rear wheel speed sensor WSSR output pin
2	FRONT_WS_HI	Front wheel speed sensor WSSP input pin
3	CAN_HI	CAN_H pin for CAN communication
4	CAN_LO	CAN_L pin for CAN communication
5	POWER_RETURN	Board Ground (GND) pin
6	ABS_WARNING_LAMP	Output pin driving the external ABS warning lamp
7	ECU_BATTERY	12V_ECU power input pin
8	REAR_WS_HI	Rear wheel speed sensor WSSP input pin
9	FRONT_WS_LO	Front wheel speed sensor WSSR output pin
10	FRONT_BRAKE_SWITCH	Digital input pin for customized braking action triggers
11	REAR_WS	Rear wheel speed signal output pin
12	ECU_WAKE	Wake-up input pin
13	FRONT_WS	Front wheel speed signal output pin
14	MOTOR_BATTERY	12V_Motor power input pin

2. **MSPM0 serial wire debug (SWD) interface**: The MSPM0 SWD interface is used for programming and debugging. Figure 4-3 shows the connection between the MSPM0G-series MCU SWD port and a standard JTAG connector.

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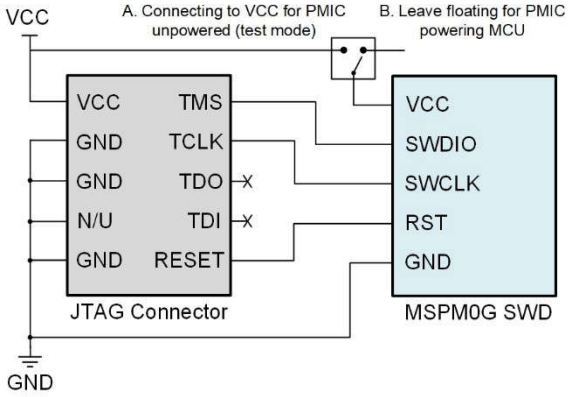


Figure 4-3. JTAG and MSPM0G Connection

3. **Valve pins and indicator LEDs**: Four pairs of connectors are provided to interface with the solenoid valves. To facilitate testing and evaluation in the absence of physical valves, integrated indicator LEDs are provided. These LEDs are driven by the DRV81646-Q1 channel status, allowing the user to verify driver switching logic independently of the valve load.
4. **Pump motor pins and indicator LED**: The board includes connectors for the pump motor. Similar to the valve control, an indicator LED is provided to monitor the pump motor HSS status as controlled by the DRV8106-Q1. This allows for functional verification of the motor driver without requiring a physical pump motor connection.
5. **Testing Jumpers**: Connecting the jumpers to short ECU_WAKE or FRONT_BRAKE_SWITCH to 12V_ECU to simulate active inputs.
6. **Reserved SPI**: One MSPM0G SPI instance is routed to external headers to accommodate potential expansion requirements or additional peripheral integration (such as external sensors).
7. **XDS110 debugging tools**: Connecting the XDS110 board to the SWD pins for real-time debugging and code flashing. LP-XDS110 Development kit | TI.com.
8. **Code Composer Studio (CCS) IDE**: Development and debugging are performed using the CCS IDE, which can be downloaded from the TI website (CCSTUDIO IDE, configuration, compiler or debugger | TI.com).

4.4 Test Results

This section presents the experimental results obtained from testing the system components. The evaluation covers the power-on sequence, steady-state performance, functional characteristic waveforms, transient response waveforms, and the thermal performance.

4.4.1 TPS65388x-Q1 Test Results

4.4.1.1 Power on Sequence of the TPS65388x-Q1

Following the power tree design described in Section 3.1, once the PMIC receives the WAKE-UP signal, it enters the INIT mode followed by PWRU_SEQ mode. The power-up (PU) and power-down (PD) sequences are highly configurable through NVM.

In this reference design, the NVM information for the PU and PD sequences is detailed in Table 4-2, and the corresponding partial waveforms are illustrated in Figure 4-4.

- **Yellow waveform:** PMIC WAKE-UP signal
- **Blue waveform:** LDO1 output (3.3V)
- **Purple waveform:** LDO2 output (5V)
- **Green waveform:** HV_BUCK output (6V)

Table 4-2. PU Sequence and PD Sequence Configuration for the TPS65388x-Q1 NVM

Function	PU Slot	PU Slot Duration	PD Slot	PD Slot Duration
HV-BUCK (6V)	NA	NA	NA	NA
LDO1 (3.3V)	Slot 0	2ms	Slot 7	8ms
LDO2 (5V)	Slot 1	2ms	Slot 6	8ms
LDO3 (1.65V)	Slot 2	2ms	Slot 5	8ms

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Table 4-2. PU Sequence and PD Sequence Configuration for the TPS65388x-Q1 NVM (continued)

Function	PU Slot	PU Slot Duration	PD Slot	PD Slot Duration
PLDO1 (3.3VP)	Slot 3	2ms	Slot 4	8ms
GPIO1 (P-FET control for 12V_Motor)	Slot 4	2ms	Slot 3	8ms
GPIO2 (P-FET control for 12V_ECU)	Slot 5	2ms	Slot 2	8ms
EXT_VMON1 (12V_Load)	Slot 6	2ms	Slot 1	8ms
EXT_VMON2 (12V_Pump)	Slot 7	2ms	Slot 0	8ms

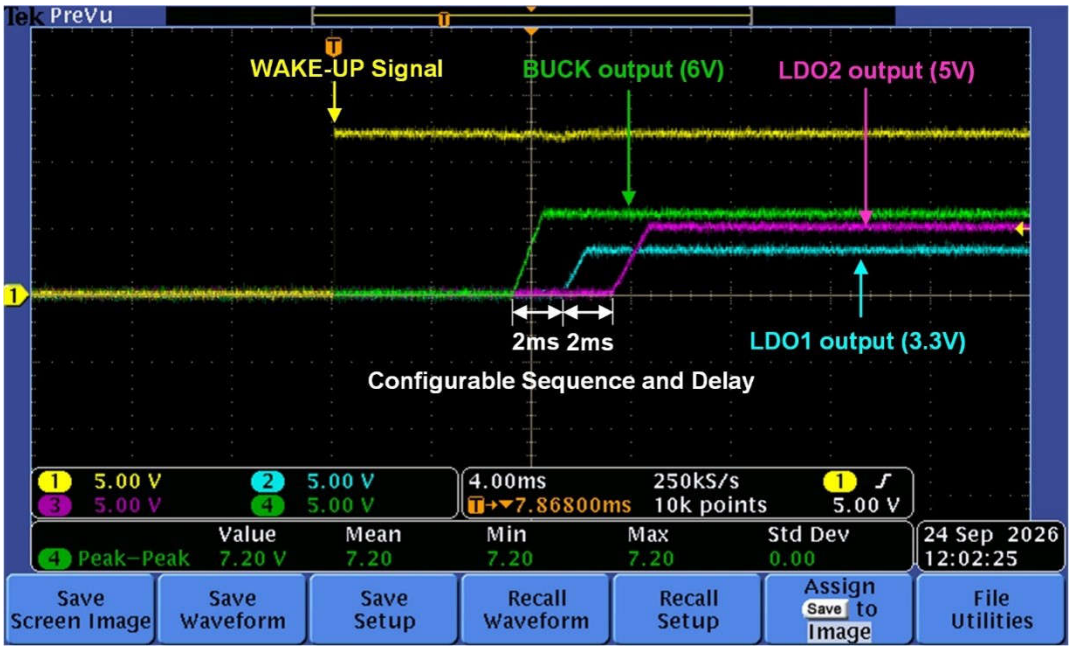


Figure 4-4. TPS65388x-Q1 Power-on Sequence.

4.4.2 TPS1200-Q1 Test Results

4.4.2.1 TPS1200-Q1 Turn-On Characteristics

Figure 4-5 shows the turn-on waveforms for the TPS1200-Q1. Upon assertion of the PWM signal, the TPS1200-Q1 drives the output high, charging the external HSS input capacitance (Ciss) to initiate turn-on.

To optimize EMI performance and minimize switching node ringing, the turn-on speed can be tuned using an appropriate gate resistor. This is particularly effective for this application, as high-frequency HSS switching is not a primary requirement.

- **Blue waveform**: HSS output voltage (12V_Load)
- **Purple waveform**: PWM control signal for TPS1200-Q1
- **Red waveform**: HSS VGS gate-drive signal

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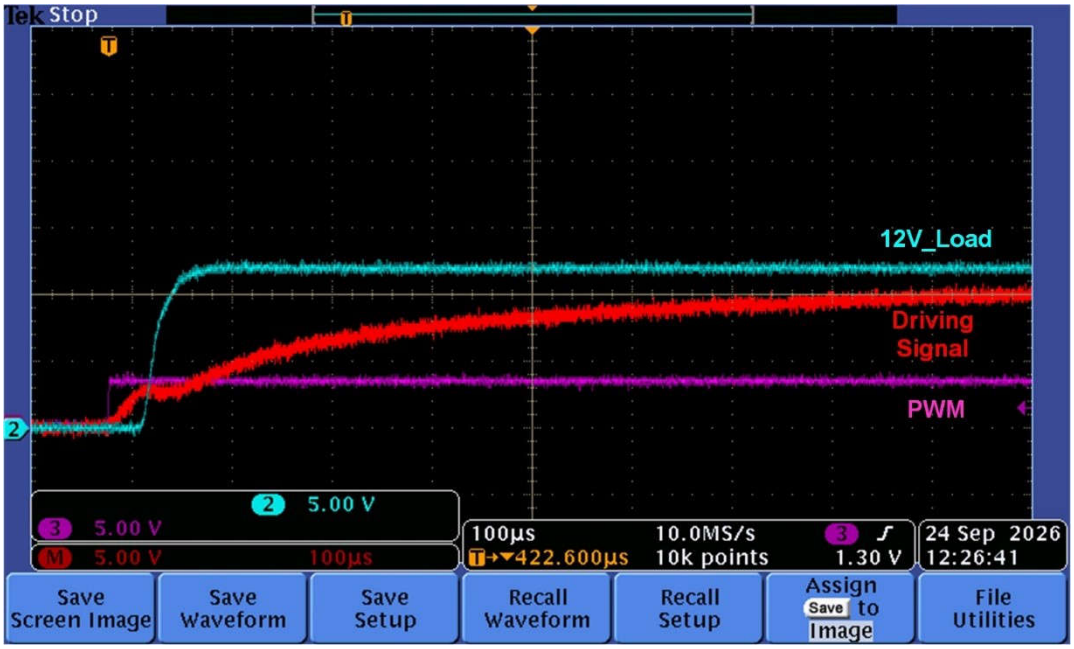


Figure 4-5. TPS1200-Q1 Turn ON Waveforms.

4.4.3 Solenoid Valves Test Results

4.4.3.1 Solenoid Valves Turn-On and Turn-Off Waveforms

In this reference design, four solenoid valves are controlled by the DRV81646-Q1 at a frequency of 15Hz. Figure 4-6 shows the key operating waveforms for a single solenoid valve.

- **Yellow waveform:** Output from one channel of the INA4181-Q1, representing the solenoid valve current during the ON state. At a 12V input, the typical steady-state ON-state current of the selected solenoid valve in this reference design is 2.2A.
- **Blue waveform:** One of the four PWM control signals from the MCU to the DRV81646-Q1.
- **Purple waveform:** The output voltage of one of the four DRV81646-Q1 output pins.

To protect the system against inductive voltage transients during fast current cutoff, a 24V TVS diode is connected between the VCLAMP pins and the 12V_Load. As shown in the results, the maximum VOUT is clamped at 43.2V, which is well within the DRV81646-Q1 maximum rated voltage of 65V.

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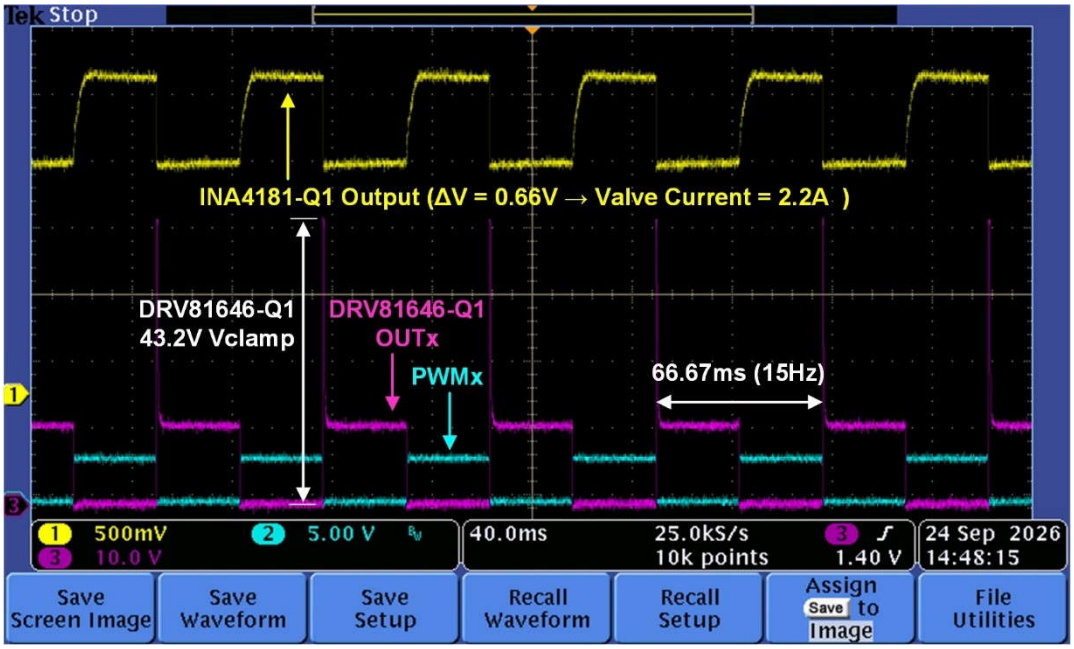


Figure 4-6. Solenoid Valve Operation Waveforms

Figure 4-7 shows the waveforms during the solenoid valve turn-off transient. When the PWM signal transitions to a low state, the valve current is routed through the DRV81646-Q1 internal body diode to the VCLAMP pin, where it is then shunted through the external TVS diode for fast decay. As shown in the results, the current decay is within 2.55us. The TVS diode conducts for approximately 335us to complete the current cutoff. Additionally, a 100kΩ resistor is connected in parallel with the TVS diode to discharge any residual voltage across the TVS once it ceases conduction.

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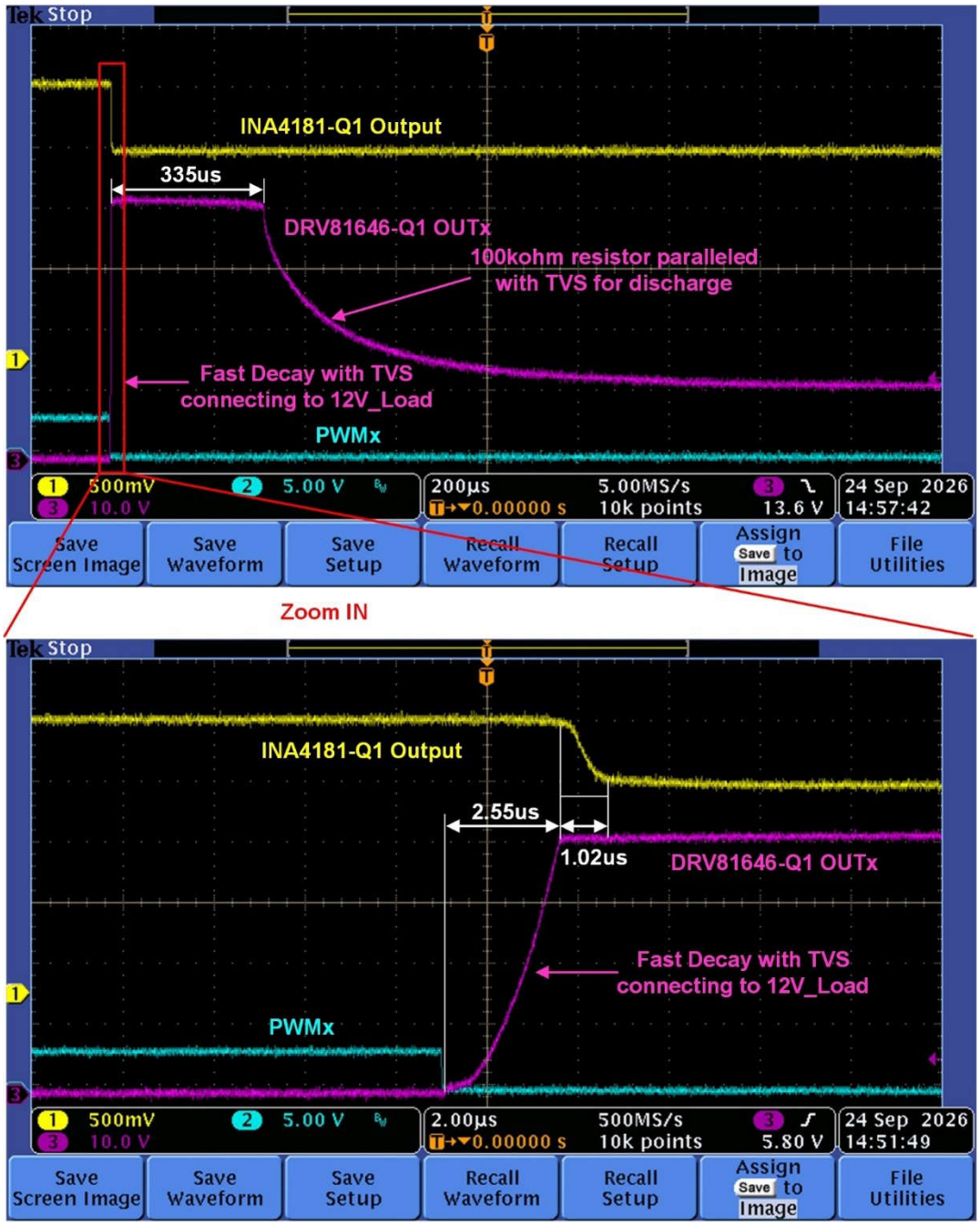


Figure 4-7. Solenoid Valve Turn OFF Waveforms

Figure 4-8 shows the solenoid valve turn-on transient waveforms. The DRV81646-Q1 turn-on slew rate is configured to 12.8V/us by connecting a 44.2kΩ resistor to the RSLEW pin.

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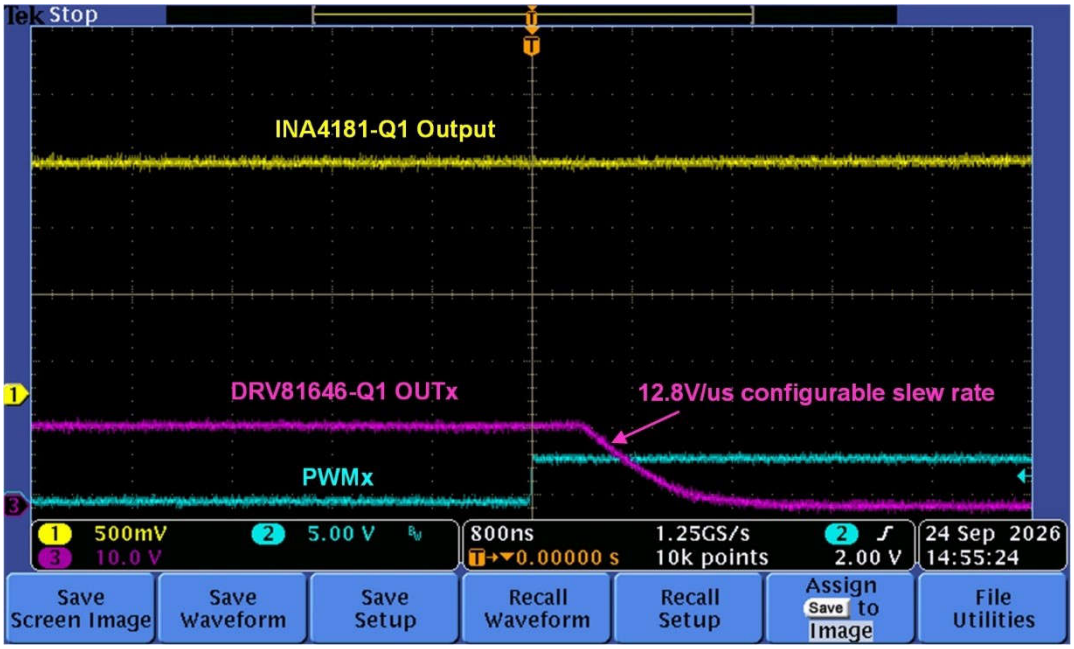


Figure 4-8. Solenoid Valve Turn ON Waveforms

4.4.4 Pump Motor Test Results

In this reference design, the pump motor was evaluated under both discrete operating mode (1Hz) and continuous operating mode (15Hz). Note that because this evaluation environment lacks a physical hydraulic structure, the mechanical load damping is lower than that of a real-world pump motor assembly.

- **Yellow waveform:** DRV8106-Q1 sensing output (SO) pin, representing the pump motor current
- **Blue waveform:** Pump motor voltage
- **Purple waveform:** DRV8106-Q1 PWM input signal
- **Red waveform:** DRV8106-Q1 gate-drive signal (VGS) for the external MOSFET

4.4.4.1 Turn ON/OFF Waveforms of the Pump Motor with Discrete Operation Mode

Figure 4-9 shows the pump motor waveforms during discrete operation at 1Hz. When the PWM signal is asserted high, the pump motor initiates rotation, resulting in an inrush transient current of approximately 21.6A with 62mA gate driving current. This inrush transient current can be further limited by decreasing the DRV8106-Q1 gate driving strength. As the motor reaches its operating speed, the current stabilizes at a steady-state value of approximately 2.13A. When the PWM signal transitions to low, the motor decelerates due to mechanical torque, generating a deceleration electromotive force (EMF) as shown in the blue waveform.

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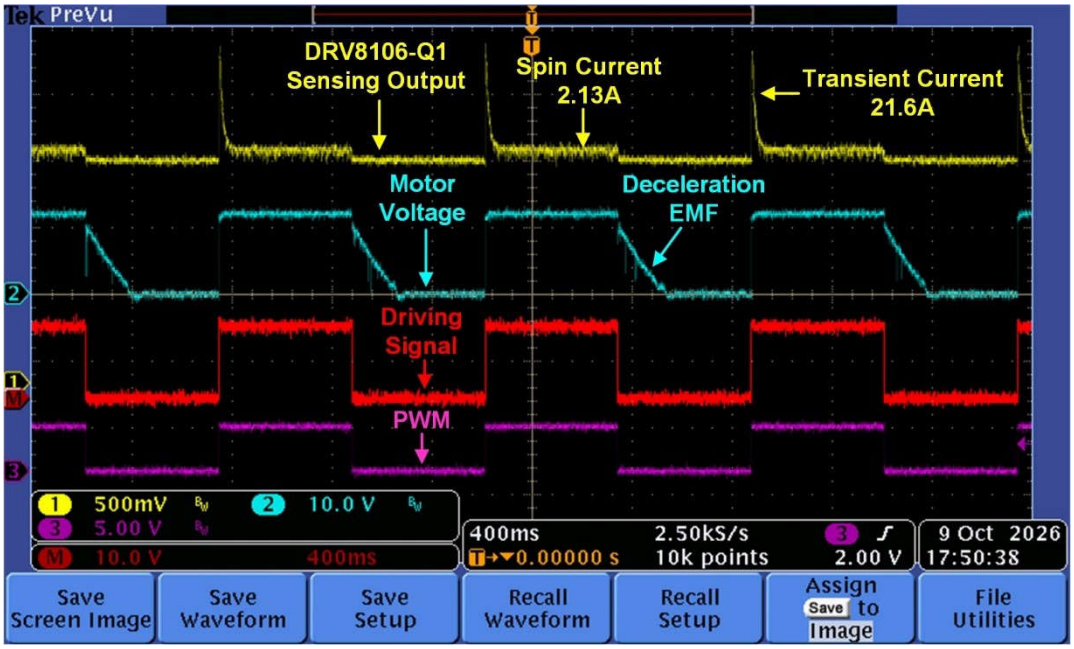


Figure 4-9. Pump Motor Discrete Operation Mode Waveforms (1Hz)

4.4.4.2 Turn ON/OFF Waveforms of the Pump Motor with Continuous Operation Mode

Figure 4-10 shows the waveforms of the pump motor in continuous operating mode at 15Hz. Compared to the discrete mode, the peak transient current is significantly lower because the motor does not have sufficient time to decelerate between cycles; the mechanical momentum maintains a higher base speed.

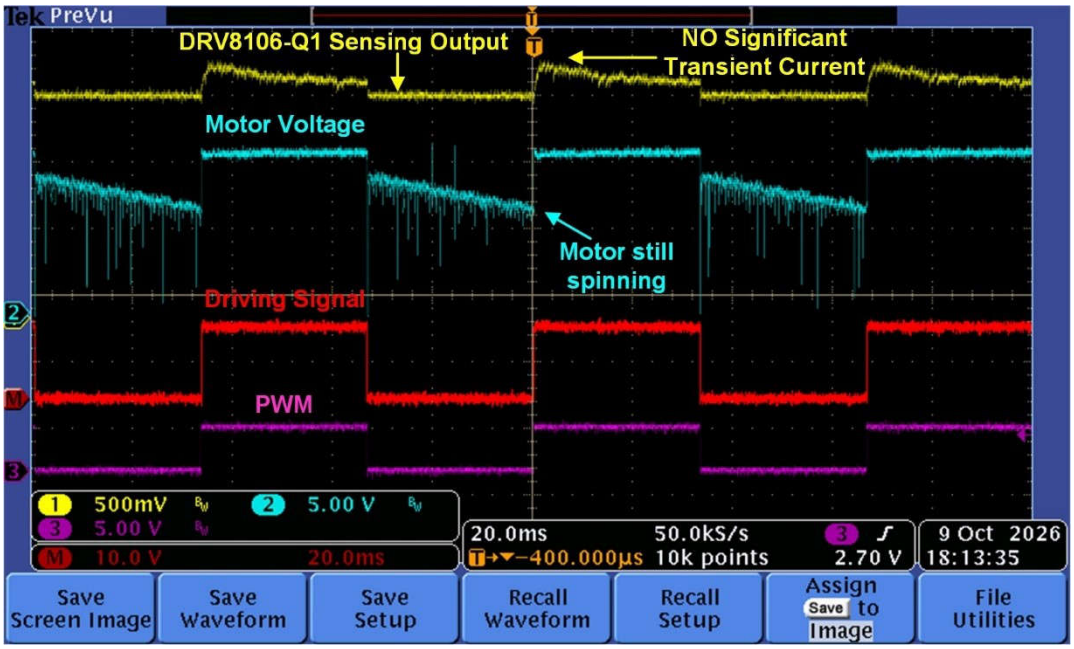


Figure 4-10. Pump Motor Continuous Operation Mode Waveforms (15Hz)

Figure 4-11 shows the turn-off transient characteristics of the pump motor. When the PWM signal transitions to low, the HSS of the pump motor is turned off. The motor current is then conducted through the paralleled diode, which clamps the motor voltage to the negative diode's forward voltage VF. Once the motor current decays to zero, the diode ceases conduction, and the motor voltage becomes equal to the generated EMF, which is proportional to the motor's rotational speed.

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In this reference design, the turn-on and turn-off driving strength of the DRV8106-Q1 is configured to 62mA through the SPI, as observed in the red waveform.

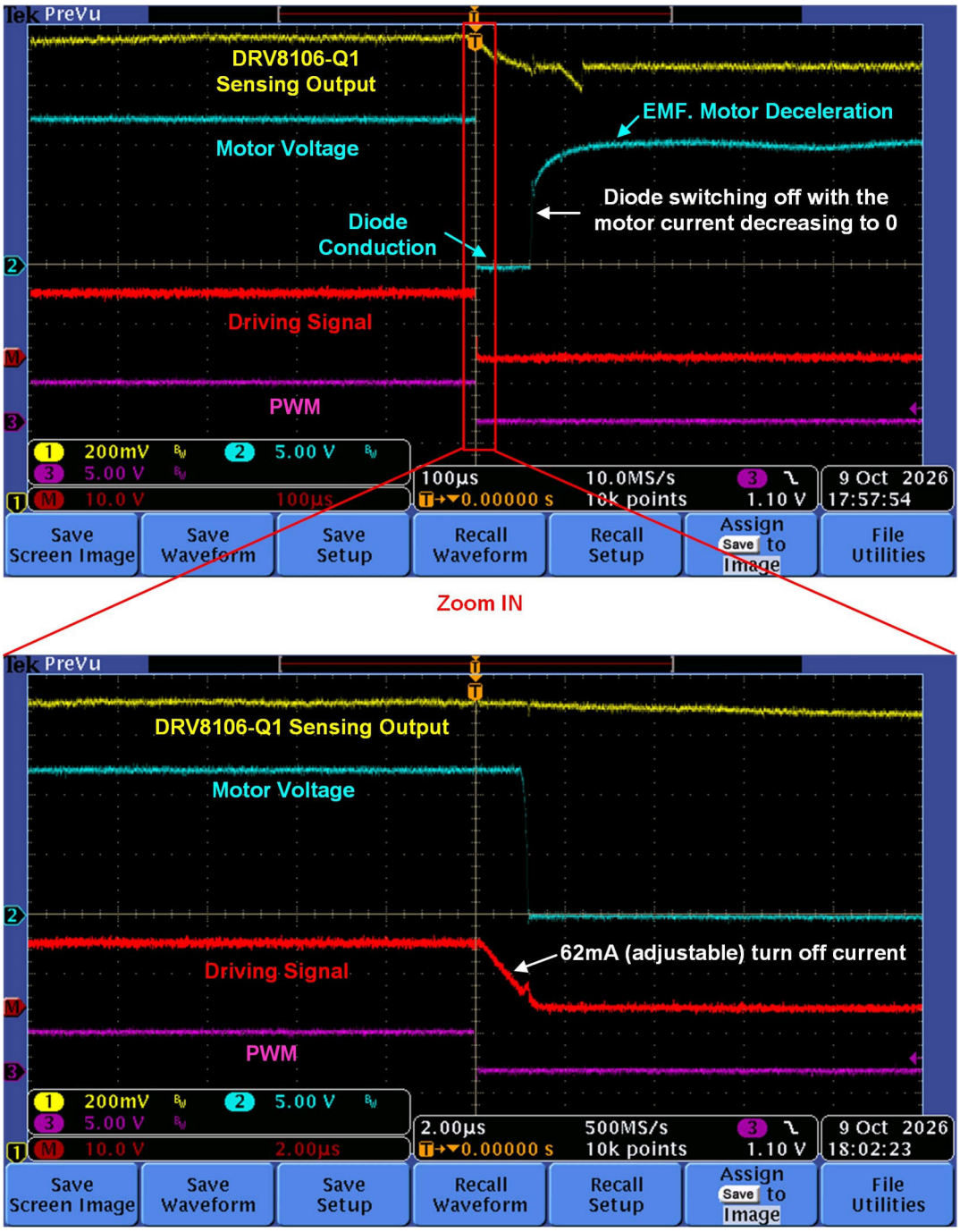


Figure 4-11. Pump Motor Turn OFF Waveforms

4.4.5 WSS001-Q1 Test Results

WSS001-Q1 outputs the sensor speed signal from WSSO output for MCU to measure the wheel speed and sensor signal decoded result is stored in internal register bits that can be accessed through SPI. Figure 4-12 shows the WSS001-Q1 output signals when driven by both PWM-mode and AK-mode inputs from an external wheel speed sensor. In these waveforms, the purple waveform represents the raw external wheel speed sensor output, while the green waveform represents the processed WSS0 output signal from the WSS001-Q1.

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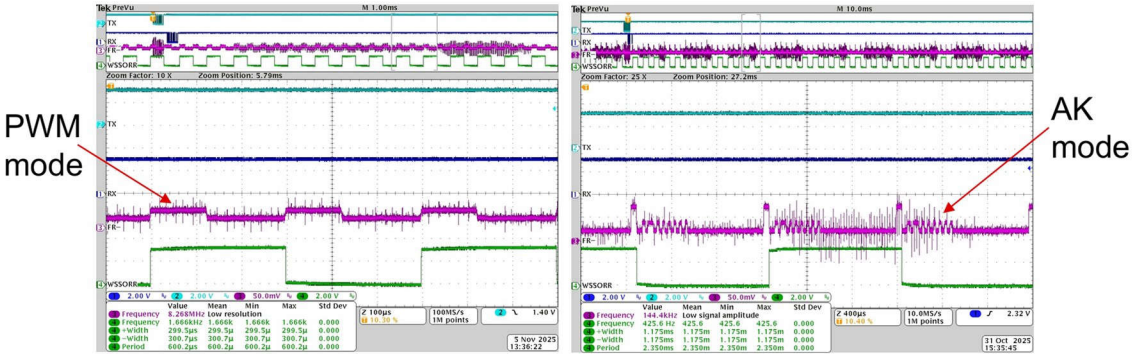


Figure 4-12. WSS001-Q1 Output Supporting Both PWM Mode and AK Mode

4.4.6 Thermal Performance

Figure 4-13 presents the thermal profile of the reference design board under active load. As the primary heat source on the PCB due to high current conduction, the DRV81646-Q1 was closely monitored during thermal testing. The thermal imaging was captured while all four channels of the DRV81646-Q1 were operating at a frequency of 15Hz with a steady-state ON-state current of approximately 2.2A per channel. It takes approximately 1.5 minutes to reach the thermal steady dtate, and the DRV81646-Q1 exhibited a steady-state temperature rise of 83.9°C. The PMIC, which provides power to all subsystems, exhibited a steady-state temperature rise of 49℃. These results demonstrate the thermal robustness of the design under typical valve operating mode.

Note that the temperature of the DRV81646-Q1 is related to the input voltage, valve parameters (inductor and resistor), PWM frequency, PWM duty cycle, continuously operating time, and cooling design. The power dissipation and thermal performance could be estimated in the development stage.

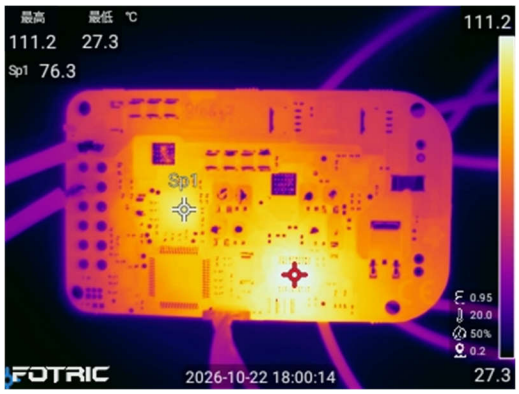


Figure 4-13. Thermal Profile With DRV81646-Q1 4 Channels Actuating

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5 Design and Documentation Support

5.1 Design Files

5.1.1 Schematics

To download the schematics, see the design files at TIDA-020111.

5.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-020111.

5.1.3 PCB Layout Recommendations

5.1.3.1 Layout Prints

To download the layout prints for each board, see the design files at TIDA-020111.

5.2 Tools and Software

- CCSTUDIO Code Composer Studio Integrated Development Environment
- MSPM0-SDK MSPM0 MCU MSPM0 software development kit (SDK)
- TMDSEMU110-U XDS110 JTAG Debug Probe

5.3 Documentation Support

1. Texas Instruments, MSPM0 G-Series MCUs Hardware Development Guide, application note
2. Texas Instruments, MSPM0 G-Series 80MHz Microcontrollers, technical reference manual

5.4 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need. Linked content is 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.

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6 About the Author

YUXIN LIU is a System Engineer at Texas Instruments, System Engineering and Marketing (SEM) team. His work focuses on automotive traction inverter and chassis end-equipment. He earned his master's degree in electrical engineering from Shanghai Jiao Tong University in 2024.

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