

Achieving Functional Safety Goals for DC/DC Converters Using F29x



Shawn Li, Sifan You, Hely Zhang

ABSTRACT

The Electro-Mechanical Brake (EMB) system represents the ultimate design for brake-by-wire technology. The electronic components at each braking node can meet the ASIL-D Safety Integrity Level. For the power supply part, the conventional design is to use an external voltage monitor to directly use an ASIL-D rated Power Management IC (PMIC) or Buck converter. However, such devices are limited in availability on the market and come at a high cost.

This article proposes a system-level functional safety design: a TI F29x MCU is used as the monitoring unit, leveraging the Comparator Subsystem (CMPSS) to perform real-time monitoring of the output voltage of the ASIL-C rated LM686x5-Q1. Upon detection of undervoltage or overvoltage faults, the MCU actively issues a shutdown signal to rapidly cut off the fault, thereby helping the overall power supply system to achieve ASIL-D compliance.

Table of Contents

1 Introduction	2
2 Hardware Design	3
3 Software Design	6
4 Test Results	7
5 Summary	10
6 About the Authors	11
7 References	12

Trademarks

All trademarks are the property of their respective owners.

1 Introduction

In an EMB system, the reliability of the power supply is critical to system safety, directly affecting the safety of the vehicle and the driver. The ISO 26262 standard classifies Automotive Safety Integrity Levels into four grades from ASIL-A to ASIL-D, with ASIL-D being the highest. The LM686x5-Q1 is an ASIL-C rated Buck converter and incorporates multiple built-in hardware protection features, such as Overvoltage Protection (OVP), Overcurrent Protection (OCP), and Thermal Shutdown (TSD). However, it does not include output Undervoltage Protection (UVP) and therefore cannot cover output voltage drop faults caused by factors such as sudden load surges, supply instability, or a short circuit in the low-side switch of the synchronous Buck converter. This gap must be addressed by an external safety mechanism.

To address the safety blind spots, the multiple CMPSS modules built into the F29x provide an ideal external independent safety monitoring design. The CMPSS consists of two independent analog comparators — a high-side comparator (CMPH) and a low-side comparator (CMPL) — each paired with a dedicated 12-bit internal DAC, forming a hardware window comparator capable of continuously and real-time monitoring the divided voltage signal of VOUT. Once the CMPSS detects an OV or UV event, the output can be routed directly to a GPIO pin through the Output X-BAR. Without any CPU intervention, a low signal can be driven on the GPIO within microseconds to pull down the EN or nSTB pin of other devices in the signal chain, completing active shutdown protection. Together with the LM686x5-Q1, this forms a power supply system compliant with ASIL-D requirements.

2 Hardware Design

In a conventional power supply system, an additional voltage monitor is typically placed at the output of the Buck converter. As shown in [Figure 2-1](#), the TPS3762-Q1 is a 65V input voltage monitor featuring high accuracy, fast detection time, and a built-in self-test function. This device can be directly connected to a 12V/24V system to continuously monitor overvoltage and undervoltage conditions, and can help the LM68645-Q1 achieve ASIL-D compliance. However, this design increases system cost and design complexity. Therefore, this article proposes an optimized solution that reduces system cost and simplifies the design.

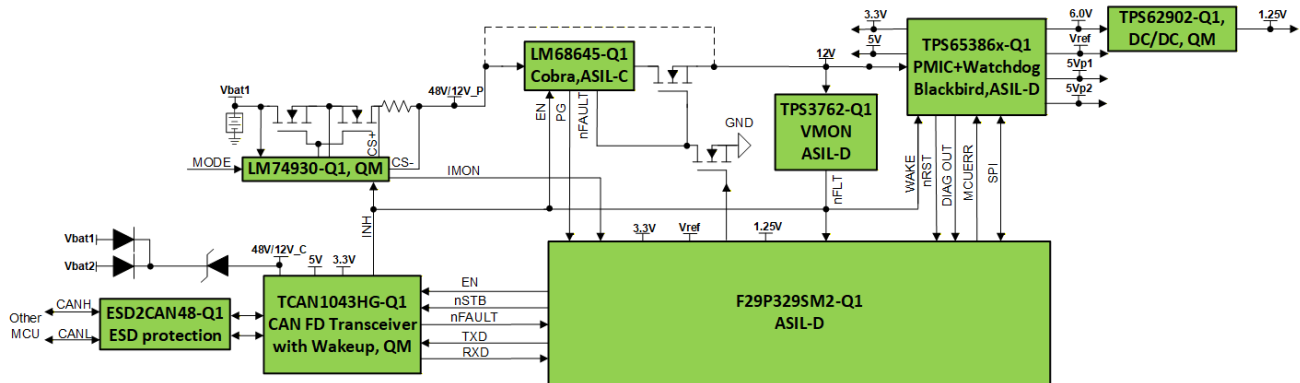


Figure 2-1. Conventional Design Block Diagram

[Figure 2-2](#) shows the block diagram of the optimized power supply system. The TCAN1043HG-Q1 is a CAN FD transceiver with an INH output, which can be used to selectively enable various power supplies that may be present on the node. The LM74930-Q1 is an ideal diode controller that drives and controls a pair of external back-to-back NMOS to provide reverse polarity protection and reverse current blocking. The LM68645-Q1 is the DC/DC converter that is the primary focus of this article; the converter features a controllable EN pin that allows shutdown through external control. The F29P32-Q1 is the MCU highlighted in this article: it not only supports up to ASIL-D, [YS1] but also integrates CMPSS comparators capable of monitoring and protecting the output voltage of the LM68645-Q1.

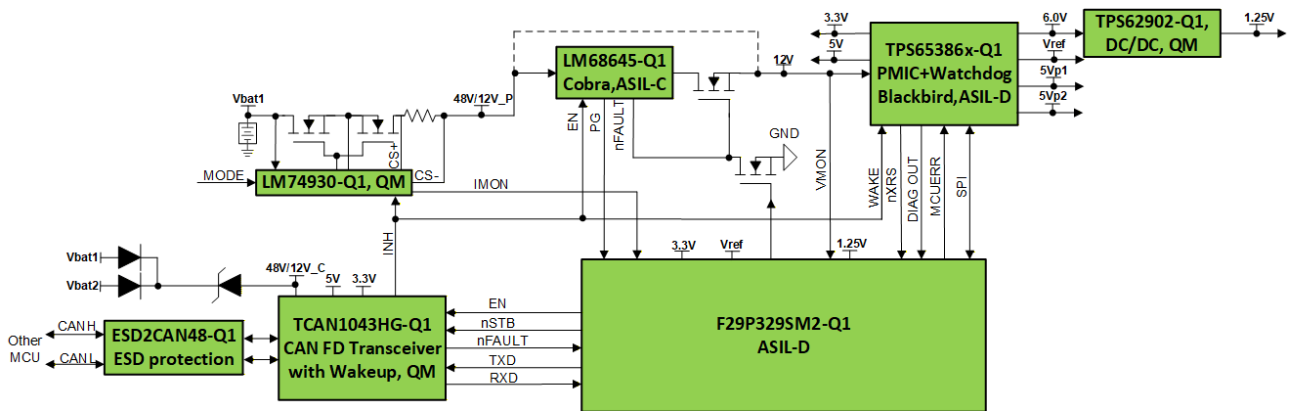


Figure 2-2. Optimized Design Block Diagram

[Figure 2-3](#) shows the schematic of TCAN1043HG-Q1. TCAN1043xx-Q1 meets the physical layer requirements of the ISO 11898-2 (2016) High-Speed Controller Area Network (CAN) specification, providing an interface between the CAN bus and the CAN protocol controller. These devices support both classical CAN and CAN FD

protocols, with data rates of up to 2 Mbps. EN_CAN is the signal used by the MCU to control the EN pin of the transceiver. During the early power-up phase, before the MCU has completed initialization, EN_CAN is held low. However, within the tUV time window, the INH pin defaults to a high output, which enables the DC/DC converter and PMIC, ensuring that all power supply rails output normally so that the MCU can operate correctly. The MCU then uses this tUV time window to set EN_CAN high, thereby keeping INH_CAN at a high level.

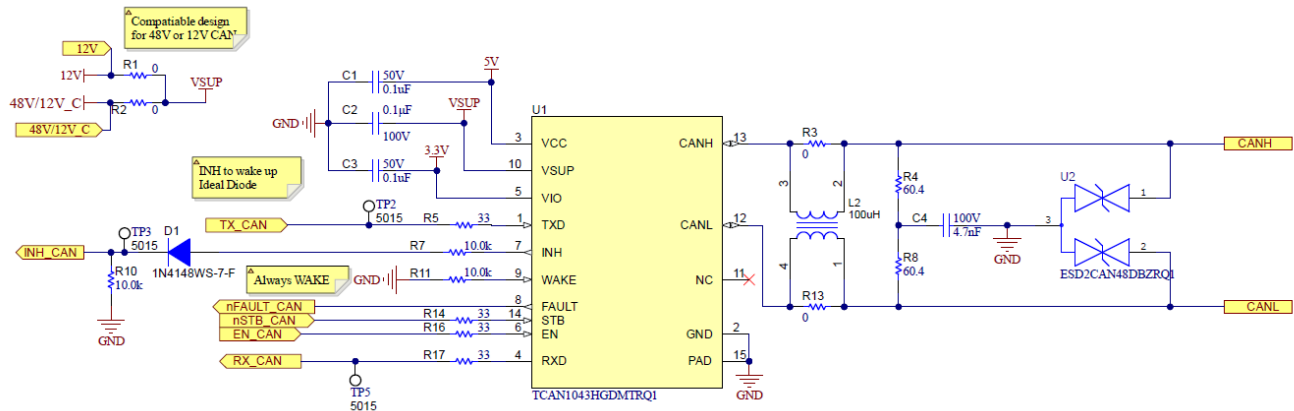


Figure 2-3. TCAN1043HG-Q1 Schematic

Figure 2-4 shows the schematic of LM74930-Q1, which controls Q1 and Q2 to achieve switching control of the input voltage to the downstream Buck converter, while also providing overcurrent and overvoltage protection. The wide input supply voltage range of 4V to 65V enables protection and control of ECUs powered by 12V and 24V automotive batteries. The device can withstand and protect the load against negative supply voltages as low as -65V. Its EN pin is controlled by INH_CAN; pulling it below V(ENF) shuts down the drive output.

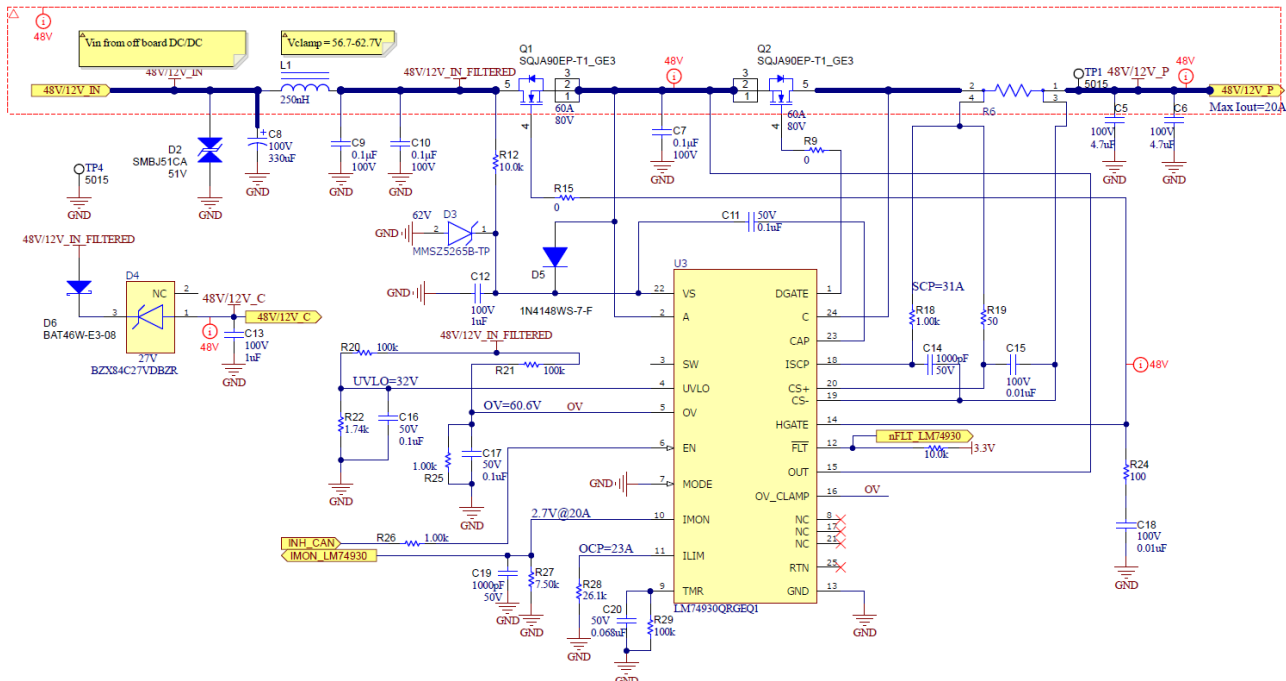


Figure 2-4. LM74930-Q1 Schematic

Figure 2-5 shows the schematic of LM68645-Q1. In this system, the converter is used to step down 48V to 12V. Its EN pin is also controlled by INH_CAN. Additionally, Q3 is added so that when the chip detects a fault, the nFAULT pin immediately outputs a low signal, turning off Q3 to protect downstream components. At the

same time, the output voltage is divided by resistors R42 and R43 to produce VMON, which is fed into the CMPSS module of the MCU for monitoring and diagnostics. If the CMPSS module detects an overvoltage or undervoltage fault, it immediately pulls nSTB low, putting the TCAN1043HG-Q1 into Sleep mode. This in turn pulls INH_CAN low, disabling LM68645-Q1, thereby preventing more serious systemic faults.

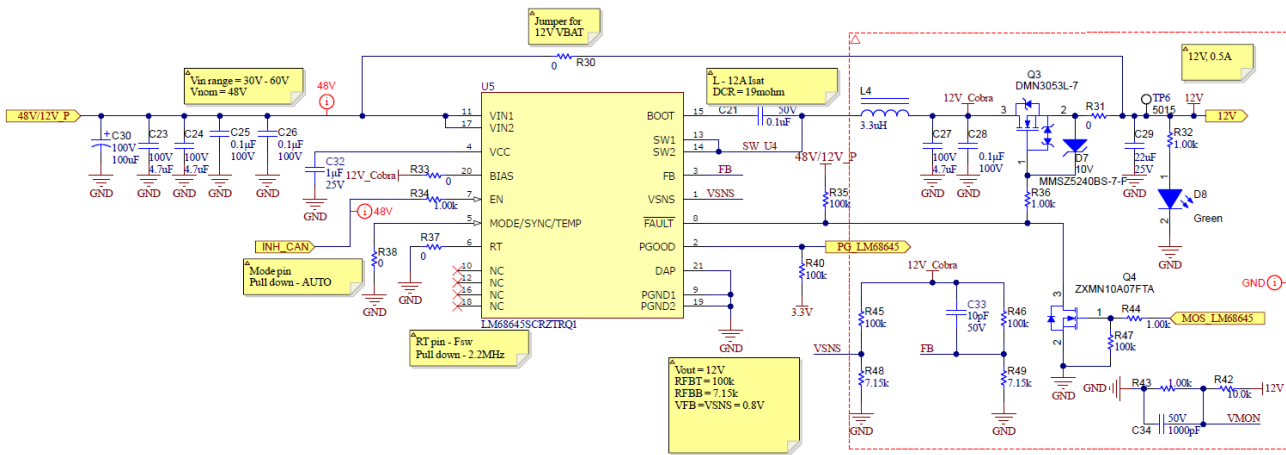


Figure 2-5. LM68645-Q1 Schematic

Figure 2-6 shows the AIO (Analog Input/Output) pin assignment diagram of F29P329SM2-Q1. Please note that VMON must be simultaneously assigned to both the high-side positive input (HP) and the low-side positive input (LP) of a CMPSS module, to achieve both overvoltage and undervoltage monitoring of the 12V rail concurrently. In this design, pin 34 is selected as the input for VMON and is assigned as CMP4_HP3 and CMP4_LP3.

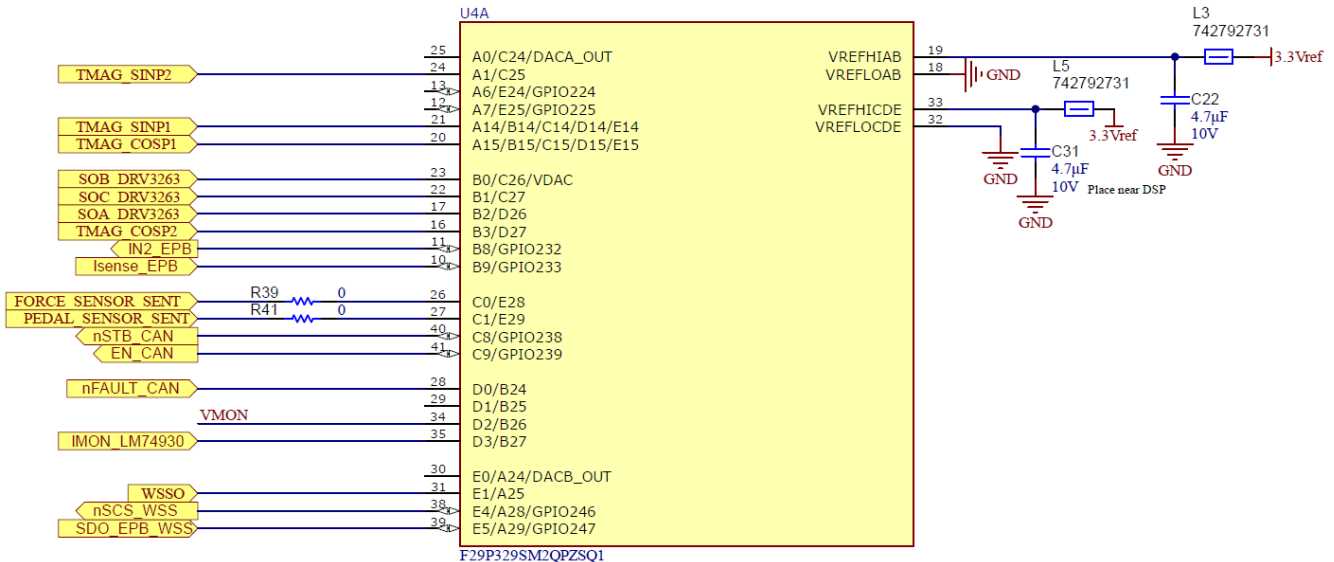


Figure 2-6. F29P329SM2-Q1 AIO Pin Assignment Diagram

3 Software Design

Figure 3-1 shows the functional block diagram of the CMPSS module inside the F29x. Each module features two independently programmable reference 12-bit DACs, which can generate digital outputs at HN and LN respectively, serving as the overvoltage threshold and undervoltage threshold. Each comparator output passes through a programmable digital filter that can remove spurious trip signals. The CTRIPOUT_x (x = "H" or "L") signals are connected to the Output X-BAR for external signaling, as shown in Figure 3-2. In this design, CTRIPOUTH and CTRIPOUTL are both routed to pin 40, which is assigned as OUTPUTXBAR6. Pin 40 ultimately outputs the nSTB_CAN signal.

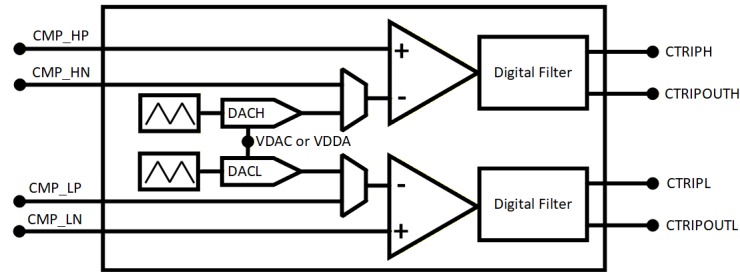


Figure 3-1. CMPSS Module Functional Block Diagram



Figure 3-2. CMPSS Module Connectivity

In this design, the rated output voltage of the Buck converter is 12V. The overvoltage and undervoltage thresholds are set at $\pm 10\%$ deviation from the rated voltage, corresponding to 13.2V and 10.8V respectively. Based on the voltage divider sampling network shown in Figure 5, the corresponding 12-bit DAC values are calculated to be 1489 and 1218. To verify that the CMPSS module can correctly detect undervoltage and overvoltage events — pulling nSTB_CAN low, which causes the TCAN1043HG-Q1 to pull INH low and disable downstream devices, the following code can be used.

```
(1)
vTimer0[0]++;
if (vTimer0[0]==10000)
CMPSS_setDACValueHigh(CMPSS4_12V_BASE,1489U);

CMPSS_setDACValueLow(CMPSS4_12V_BASE,1400U);
vTimer0[0]=0;
(2)
vTimer0[0]++;
if (vTimer0[0]==10000)
CMPSS_setDACValueHigh(CMPSS4_12V_BASE,1300U);
CMPSS_setDACValueLow(CMPSS4_12V_BASE,1218U);
vTimer0[0]=0;
}
```

In this design, the output voltage of the Buck converter remains constant at 12V. The function of code segment (1) is to change the LN value from its initial setting of 1218 to 1400 after the timer accumulates to 10000, which shifts the corresponding voltage threshold from 10.8V to 12.4V, simulating an output undervoltage condition. The function of code segment (2) is to change the HN value from the initial setting of 1489 to 1300 after the timer accumulates to 10000, which shifts the corresponding voltage threshold from 13.2V to 11.5V, simulating an output overvoltage condition.

4 Test Results

This article designs two functional safety requirements (FSR) of LM68645-Q1:

- FSR1: LM68645-Q1 shall avoid output voltage out of the maximum relative error of 10%.
- FSR2: LM68645-Q1 shall avoid output voltage out of the maximum relative error of -10%.

The safety state for both FSR is to shutdown 12V output, with an FTTI of 5ms.

This article presents experimental validation for 12V undervoltage and overvoltage events. The test conditions are as follows: rated input voltage of 48V, rated output voltage of 12V, and rated output current of 0.5A.

Figure 4-1 , Figure 4-2 and Figure 4-3 show the measured waveforms following a 12V undervoltage event — nSTB_CAN, INH, and 12V are sequentially shut down. The F29x CMPSS module's maximum output delay is 60ns, and the total low-time for nSTB_CAN and INH is 52.9 μ s. Because 12V voltage rail has 188 μ F electrolytic capacitor, 12V shutdown time is slowly 1.77ms, so the total time from the occurrence of the undervoltage event to the complete 12V shutdown is 1.82ms.

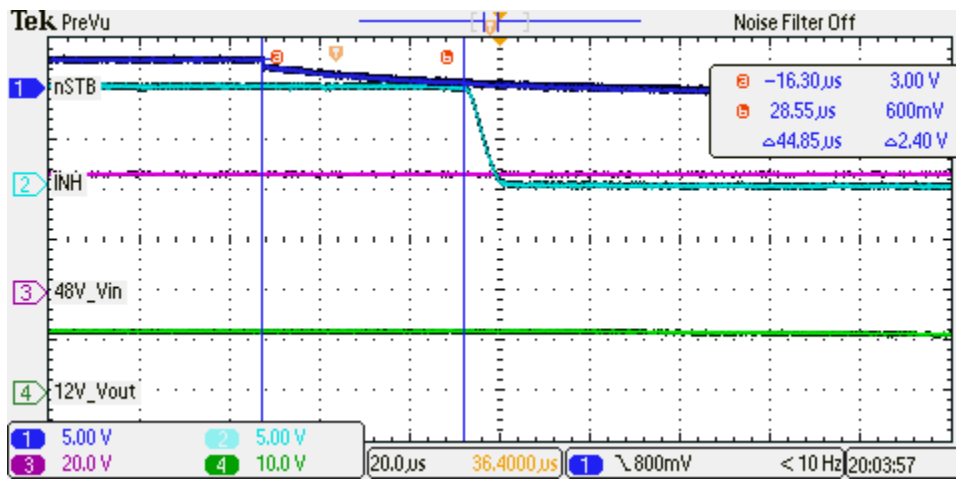


Figure 4-1. Time for nSTB to Trigger INH for UV Protection

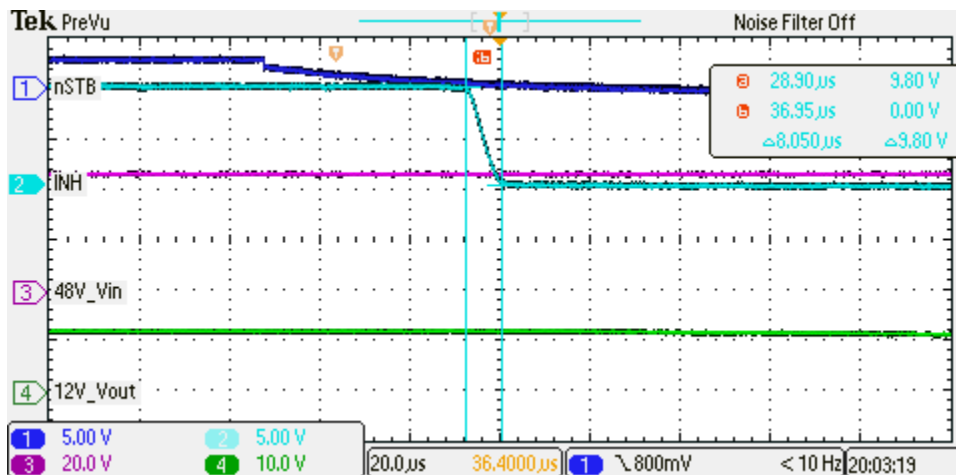


Figure 4-2. Falling Time of INH for UV Protection

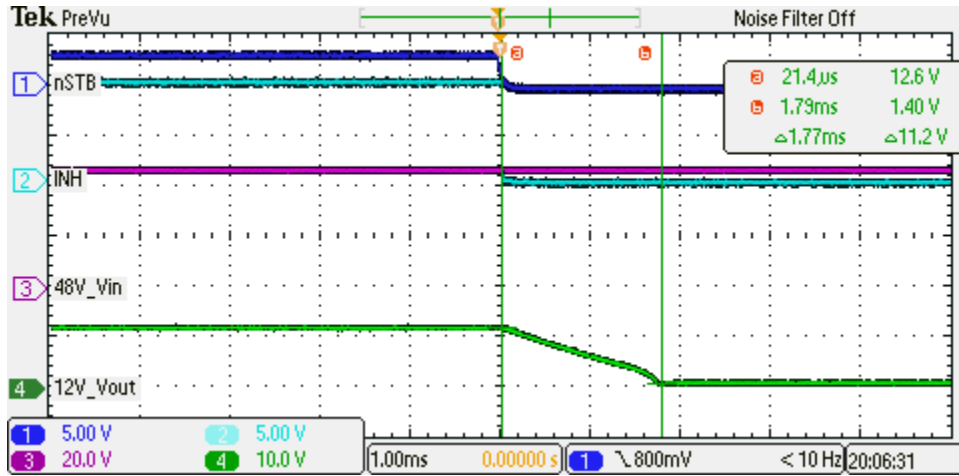


Figure 4-3. Falling Time of 12V for UV Protection

Figure 4-4, Figure 4-5 and Figure 4-6 show the waveforms following a 12V overvoltage event; the signal sequencing is identical to that of the undervoltage event, and the entire process lasts 1.98ms. The results

demonstrate that the safety mechanism in the design is verified, and the system reaches the expected safety state within the targeted FTTI.

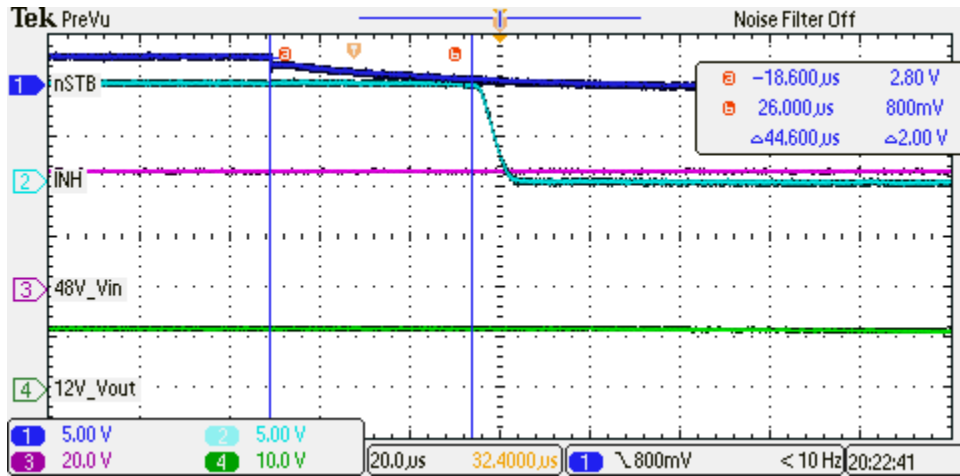


Figure 4-4. Time for nSTB to Trigger INH for OV Protection

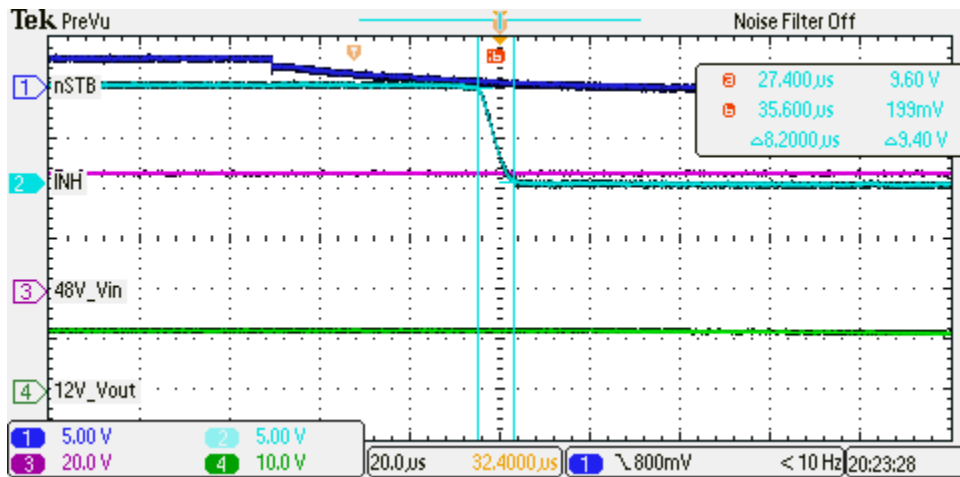


Figure 4-5. Falling Time of INH for OV Protection

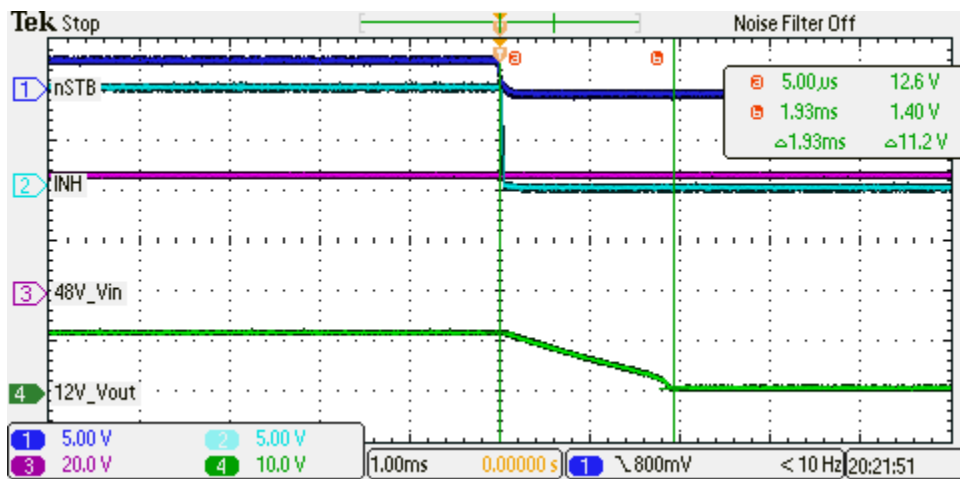


Figure 4-6. Falling Time of 12V for OV Protection

5 Summary

The Electro-Mechanical Brake (EMB) system is a novel braking technology that uses an electric motor to directly drive the braking actuator, replacing traditional hydraulic braking. This offers advantages such as fast response, high braking precision, and ease of integration with autonomous driving control systems, making this an important development direction for next-generation intelligent vehicle chassis technology. Since EMB is directly related to vehicle driving safety, this imposes extremely stringent requirements on system hardware architecture, fault detection, and response capability. To this end, this article proposes a system-level functional safety design oriented toward EMB applications. By leveraging the CMPSS module of the F29x, a fault diagnosis and safety response mechanism for the DC/DC converter has been designed to meet all safety metric requirements under ASIL-D, while simultaneously reducing system cost and simplifying design complexity.

6 About the Authors

SHAWN LI is a Field Application Engineer in Texas Instruments China's Auto Tier1 team, where he specializes in chassis, body and lighting applications in automotive. He earned his bachelor's degree and master's degree in power electronics and power transmission in South China University of Technology in 2022 and 2025, and joined TI in 2025.

SIFAN YOU is a System Engineer in Texas Instruments Automotive Systems Functional Safety & Cybersecurity team, where she specializes in HEV/EV functional safety applications. She earned her bachelor's degree and master's degree in traffic information engineering and control in Beijing Jiaotong University in 2019 and 2022, and joined TI in 2025.

HELY ZHANG is a System Engineer at Texas Instruments, where he is responsible for developing home appliance and automotive chassis reference designs, especially for those related to power electronics and motor inverters. Hely earned his master's degree from Anhui University of Science and Technology of Power Electronics and Power Transmission in 2002, and worked at General Electric and SolarEdge before joining TI.

7 References

- ISO, [ISO - ISO 26262 road vehicles functional safety](#), webpage.
- Texas Instruments, [F29H85x, F29P58x, and F29P32x Real-Time Microcontrollers](#), datasheet.
- Texas Instruments, [F29H85x and F29P58x Real-Time Microcontrollers Technical Reference Manual](#), technical reference manual.
- Texas Instruments, [LM686x5-Q1 65V, 2.5A/3.5A/4.5A, Automotive Synchronous Buck DC/DC Converters With Low-EMI Switcher Technology Optimized for Functional Safety Applications](#), datasheet.
- Texas Instruments, [TCAN1043xx-Q1 Automotive Low-Power Fault Protected CAN Transceiver with CAN FD and Wake](#), datasheet.
- Texas Instruments, [LM74930-Q1 Automotive Ideal Diode Surge Stopper With Circuit Breaker, Overvoltage Protection, and Fault Output](#), datasheet.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you fully indemnify TI and its representatives against any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#), [TI's General Quality Guidelines](#), or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products. Unless TI explicitly designates a product as custom or customer-specified, TI products are standard, catalog, general purpose devices.

TI objects to and rejects any additional or different terms you may propose.

Copyright © 2026, Texas Instruments Incorporated

Last updated 10/2025