Technical Article

How eFuses are helping drive the zone architecture revolution for software-defined vehicles

TEXAS INSTRUMENTS

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The biggest disruption in the automotive industry in the past decade is the move toward software-defined vehicles. Traditional vehicle designs had hardware-based subsystems dedicated to specific functions such as the powertrain or infotainment. With the need to upgrade car models quickly, integrating multiple functions by building modular, flexible subsystems, also known as “zones,” becomes more efficient. Instead of dedicated domain control units, cars can support two to three zonal control units with integrated functionality.

The transition to zone architectures includes the replacement of classic melting-wire fuses with semiconductor switches called eFuses. eFuses have several benefits over discrete melting fuses. They have resettable outputs that allow vehicle architects to optimize their location, as they no longer require replacement after a fault. They do not need to be easily accessible, which helps reduce cable lengths from the power source to the loads. eFuses also have improved fuse time-current characteristics with far less variability and thus the potential to reduce cable diameters, weight and cost of the wire harness. Providing additional capabilities to the power-management system improves preventive and failure diagnostics, helping manage electronic system power consumption to maximize driving ranges in electric vehicles.

Figure 1 shows the transition of melting fuses to eFuses.

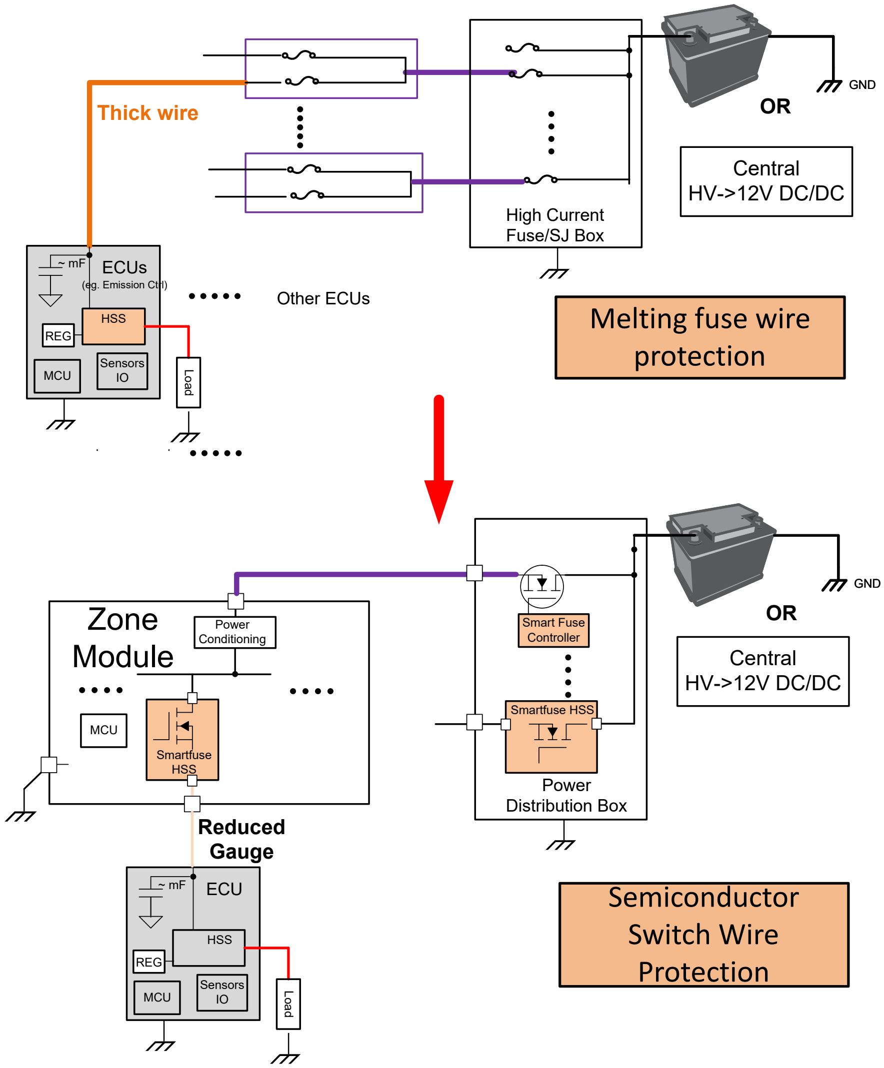

Figure 1. Melting fuse replacement in zonal controllers and power distribution boxes

In this article, I'll explain how a configurable eFuse enables a faster transition to software-defined vehicle architectures.

Designing with an eFuse

A connected car must be able to read the state of the system at all times, from advanced sensor functions down to the fuse element. In addition, zonal platforms mandate flexibility when fuse requirements change based on the load powered. An eFuse (like TPS2HCS10-Q1) can help solve both of these problems by using an interface such as Serial Peripheral Interface (SPI) to dynamically configure switches based on the load requirements and to inform decisions by reading load diagnostics. The overall system cost and component count is lower, despite the additional functionality, because eFuses do not need external passive components to configure protection and diagnostics features.

Several switch and load failure diagnostics are available continuously over SPI, reducing microcontroller (MCU) overhead. An integrated analog-to-digital converter (ADC) in the device allows full digital diagnostics readout over SPI, avoiding the need for an MCU-based ADC to read the current and voltage outputs. Figure 2 shows how an eFuse senses the output voltage and detects short-to-battery or open-load faults without external components.

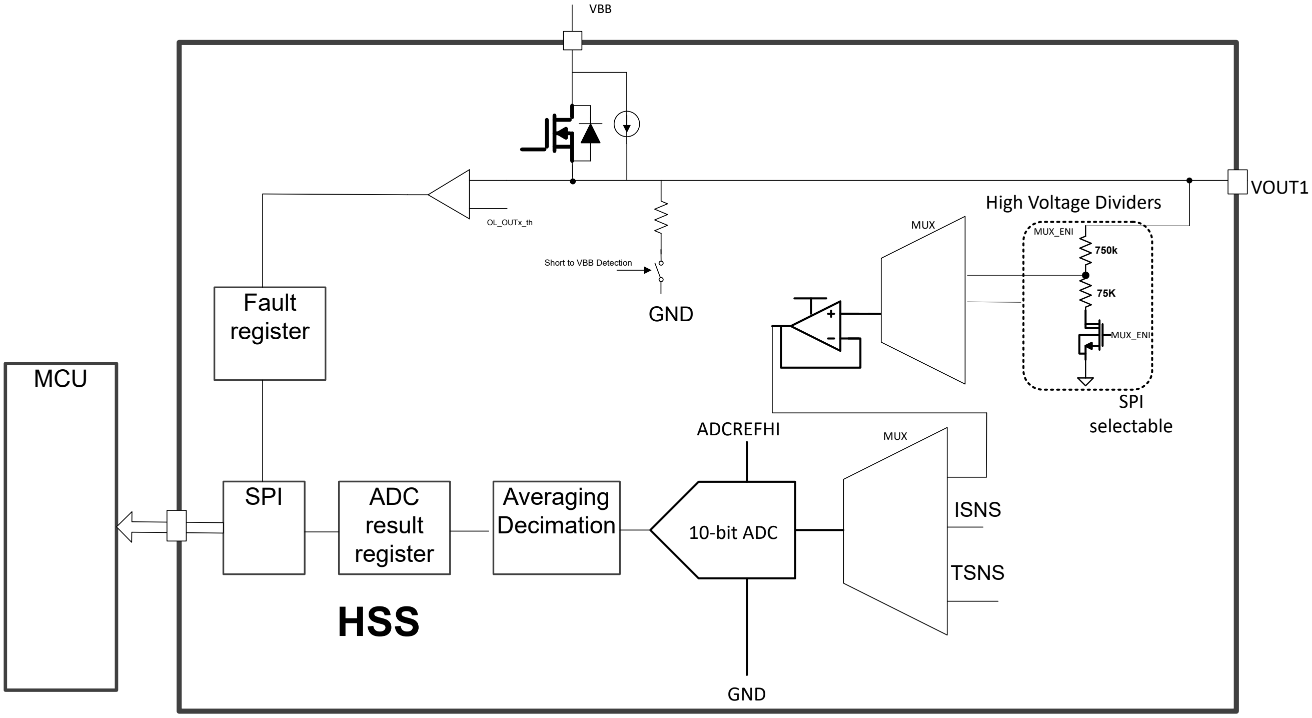

Figure 2. Output voltage sensing and short-to-battery open-load fault detection with no external components and minimal MCU overhead

One of the most challenging aspects of development when transitioning to a software-defined vehicle is streamlining software and firmware development to enable a cohesive system. Validating multiple systems for various car models adds both cycle time and cost. An eFuse scales between low and high current loads while maintaining a common interface to program and read information for multiple model variants with different output load characteristics. Having a digital interface for software configuration, control and diagnostics also lowers MCU input/output (I/O) pin requirements, reducing additional I/O expander cost and printed circuit board (PCB) area.

What makes a software configurable eFuse the good choice?

- **Configurable time-current profiles.** Rather than a standard flat current limit, an embedded fuse characteristic time-current curve determines when or if the switch turns off, depending on the time and duration of the load current. This enables the eFuse to pass high load currents (motor inrush and stall currents, for example) for brief periods, but turn off under overload conditions to protect the wire harness, PCB traces and connectors. Furthermore, SPI configuration enables a large programming range for fuse curves with just two parameters: the nominal current and shutoff energy trigger threshold. Figure 3 illustrates an example protection scheme across the full current range.

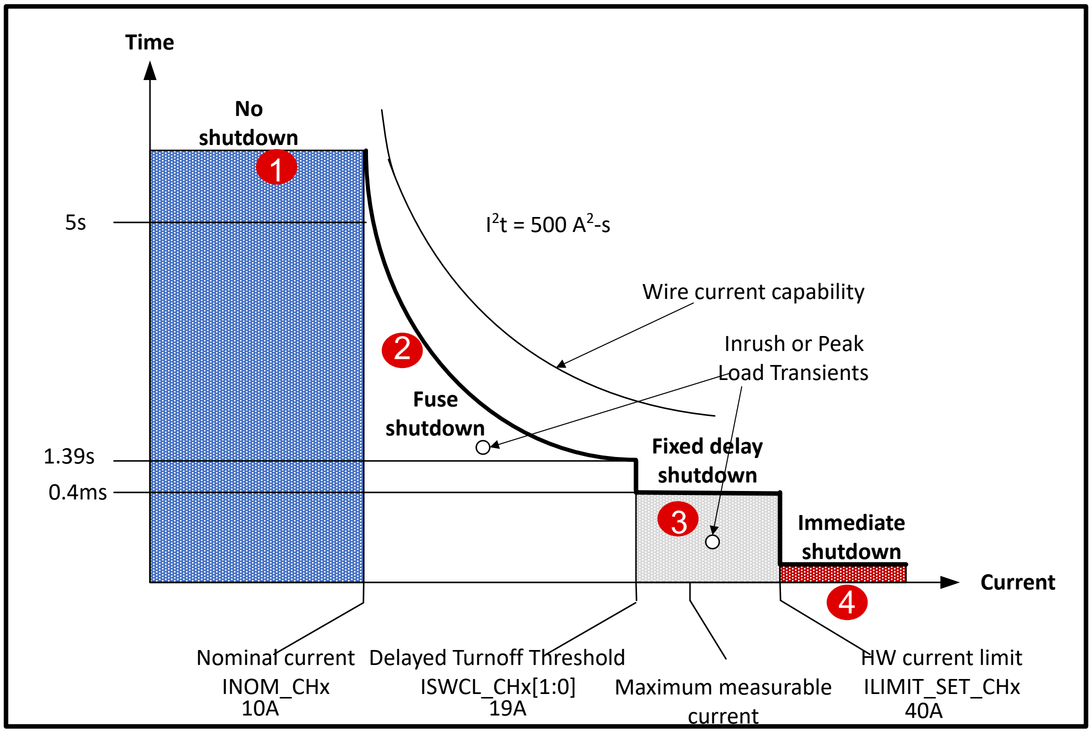

Figure 3. Programmable fuse characteristics

- **Low quiescent current.** Many electronic control units (ECUs) remain on even while the vehicle is parked. The eFuses providing power to these ECUs need to consume very low operating current so that the battery does not drain too quickly, and the necessary loads can remain active. Despite the lower current requirements, protection features remain active to keep the system protected against short-circuit events. Even more importantly, eFuses know when to switch between active and low-power settings by detecting load conditions so they can operate autonomously without adding overhead to the MCU. The TI eFuse portfolio meets all of these requirements at very low quiescent current levels.
- **Configurable capacitive load drive mode.** Many zonal loads are capacitive in nature; thus, the switches used to power them need to be capable of efficient capacitive charging. While traditional fuses and switches don't have a way to charge capacitors, eFuses offer a constant-current charging mode designed for cases where there is a significant load current during charging, or a fixed transient voltage mode for very large capacitive loads that charge with very low charging current. In either case, the inrush current is limited to a low value during a programmable charging duration. One benefit of an eFuse is that the device can drive both large and small capacitive loads by adjusting the current or voltage thresholds for charging. Configuring the device in capacitive charging mode is the best choice for the capacitance and a parallel load current draw.

eFuses are rapidly replacing traditional semiconductor switches

TI's portfolio of smart high-side switches, with integrated field-effect transistors and a wide on-resistance range for supporting diverse load currents, help alleviate the design challenges of a zone architecture. The TPS2HCS10-Q1 eFuse addresses both development and technical challenges with features such as SPI communication, low power mode, I2T current limiting and intelligent capacitor charging. These switches enable a more evolved form of power distribution while providing protective and diagnostic functions for actuator drive applications.

Conclusion

TI eFuses, including the TPS2HCS10-Q1, meet the system needs for smart power distribution and software-defined zonal ECUs while providing cost, space and time efficiencies in development. In the future, a traditional fuse in a car may never need to be replaced. as it becomes smarter and safer every day.

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