Application Brief

Fully Software Configurable High Side Switch for Power Distribution Applications in Zone Controllers

Automotive power distribution topologies are undergoing a dramatic change as domain-based vehicle architectures shift towards zone-based architectures. At the same time zonal control modules are increasingly adopting semiconductor switches for power distribution wire harness protection replacing melting fuses that are the dominant protection elements today. The main semiconductor switch benefits include:

- Re-settable outputs that allow vehicle architects to optimize the location of the fuses, because the fuses no longer require replacement after a fault and do not need to be easily accessible, and thus reduce cable length from the power source to the loads.
- Improved fuse time-current characteristic with far less variability and thus have the potential to *reduce the cable diameter, weight, and cost of the wire harness.*
- Provide additional capabilities to the power management system to improve preventative and failure diagnostics (including ECU load leakage), and help manage electronic system power consumption to improve battery electric vehicle drive range. The switch based protection aids in system power management for functional safety as well better failure diagnostics including load leakage.

The transition from melting fuses to semiconductor switches is shown in Figure 1

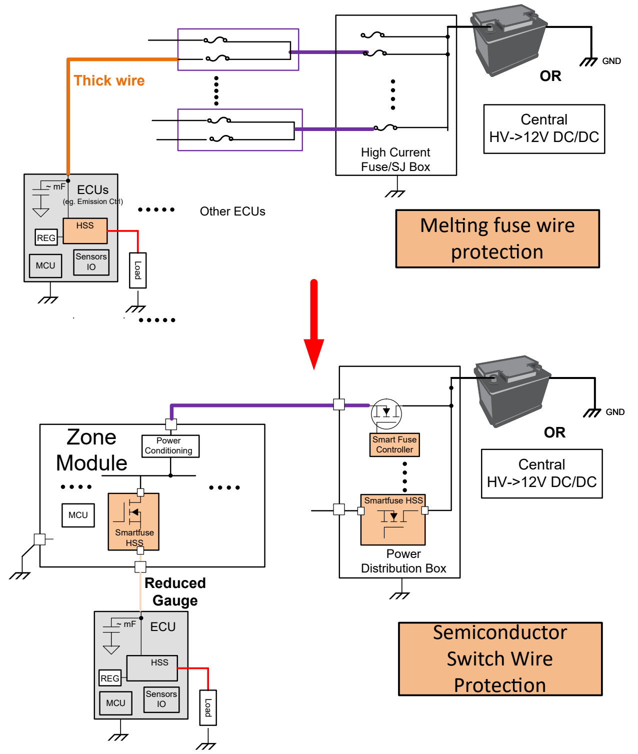

Figure 1. Melting fuse replacement in zone controllers and power distribution boxes

There are a number of challenges to overcome in semiconductor high side switches when used as smart fuse devices. These include lowering the quiescent current with the switch in the ON state and turning on outputs powering large capacitive loads typically seen at the load (Electronic Control Unit (ECU) input). Further, zone control modules and Input-Output (IO) Aggregator ECUs usually power a large variety of ECUs and actuators making the design and development a challenge. Texas Instruments is introducing a new portfolio of smart high side switches with integrated FETs and a wide Ron range addressing these concerns. The TPS2HCS10-Q1 device is the first fully software configurable device in the market that comprehensively addresses the development and technical challenges. The device incorporates all of the specific features needed for a power distribution switch as well as the traditional protective and diagnostic functions seen in high side switches for actuator drive applications.

This application brief shows how a software configurable device enables platform design of zonal controller modules as a part of the general trend where the zonal architecture paves the way to a fully software-defined vehicle. Next we discuss how the SPI configurable TPS2HCS10-Q1 device meets all the requirements like programmable fuse characteristics and low quiescent current and designed for driving any type of load-capacitive ECU loads or resistive/inductive actuator loads.

Advantages of a Fully Software Configurable Switch

The TPS2HCS10-Q1 device uses an SPI serial interface from the MCU to configure the device based on the load requirements and to read the load diagnostics. The many advantages of a software configurable switch include:

- A single platform development can suffice for the various automotive model variants with different output load characteristics. The development and validation effort is thus simplified, thus enabling a faster time to market and lower development and validation cost.
- The device can be configured in many ways offering wide programmable range in each operational mode. Examples include:
  - programmable ranges for MCU wake threshold from low quiescent mode (programmed based on ECU load)
  - off-state open load detection current threshold
  - run-time changes such as time-current fuse characteristic changing depending on the vehicle ambient temperature
  - device behavior in park (key-off) mode vs in drive mode
  - the device parameters can be changed in operation for more accurate load diagnostics. For example, the current sense ratio and ADC input gain to achieve best-in-class low current sense accuracy and resolution.
- No external passive components are needed to configure the device for protection or diagnostics. A number of switch and load failure diagnostics are available continuously over SPI reducing the MCU overhead. An integrated ADC allows full digital diagnostics readout over SPI avoiding the need for an MCU based ADC to read the current and voltage outputs. See Figure 2 that shows how the output voltage can be sensed and short-to-battery/open-load faults differentiated with no external components.Figure 1
- Digital interface for software configuration, control, and diagnostics reduces MCU IO pin requirements reducing additional IO expander cost and PCB area.

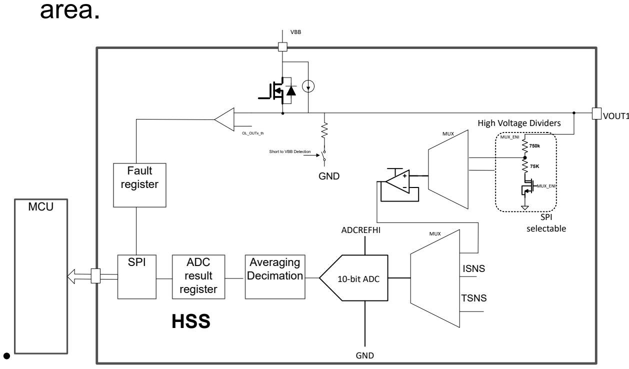

Figure 2. Output voltage sensing and short-to-battery/open-load fault detection with no external components and minimal MCU overhead

Configurable Fuse Characteristics

The TPS2HCS10-Q1 includes an embedded fuse characteristic time-current curve to determine when/if the switch turns off depending on the time/duration of the load current. This feature enables the device to pass high load currents for brief period (motor inrush and stall currents, for example), yet turn-off under overload conditions to protect the wire harness, PCB traces and connectors. The device can be compared to a melting fuse but with significantly tighter part-part variation. Further, SPI configuration in TPS2HCS10-Q1 enables a large programming range for fuse curves with just two key parameters, the nominal current and the shut-off energy trigger threshold. The nominal current is roughly equivalent of the melting fuse current rating matching DC current capability of the wire. However, unlike a melting fuse, the device offers additional options to program multiple choices of the time-current curve for a given nominal current rating. This wide range is available for each on-resistance (R_{dsON}) variant of the device family. The fuse time-current curve is then combined with a configurable delayed turn-off current based on the ADC current sense and a very fast turn-off for short circuit protection.

The overall protection scheme across the full current range is shown in Figure 3. The figure also shows how to choose the fuse curve from the programmable choices, to meet the requirements for wire protection while allowing all normal load transients to pass through.

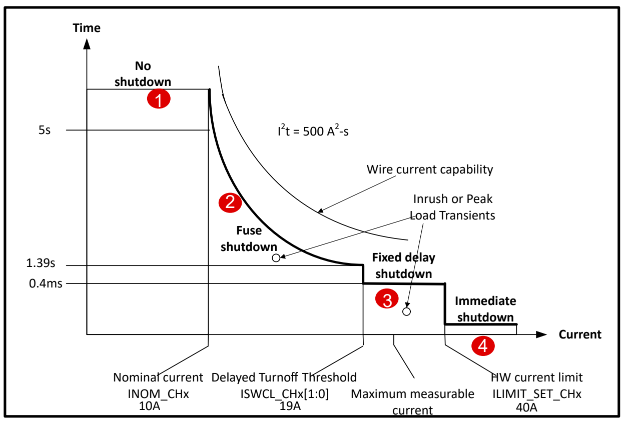

Figure 3. Programmable fuse characteristics

Low Quiescent Current Mode

There are quite a large number of ECUs that need to be powered even while the vehicle is in a park (key-off) state. Additionally, the switch that is providing power to these ECUs needs to consume very low operating current while the switch is in the ON state and providing a small amount of load current. Yet the load can demand tens or even hundreds of mAs of peak current for a short time (and low duty cycle) while performing monitoring functions. The goal of the power distribution switch is to operate in a low quiescent mode providing the peak current and when the load demands a current in excess of the peak current, switch over to the normal operation mode and signal this to the MCU.

The TPS2HCS10-Q1 device has been designed to meets all of these key requirements of the power on at all times (PAAT) switch application.

- The device can be operated with very low quiescent current (Low Power Mode or LPM) while delivering current up to maximum of a few hundred mA per channel for a short duration of the order of ms. The channel still has a relatively low R_{dsON} so that the voltage drop is less than a tens of mV in the full low power mode temperature range and part-part variation.
- Protection against short circuit at the output while in low current mode. In other words, if a short circuit were to occur with the output ON in low power mode, the device can protect itself and the wire harness.
- The device automatically responds to load current increase in any of the output channels while staying within the specification for voltage drop (and distinguishing against any short circuit). The device then sends a signal to the micro-controller to wake the zone controller (system MCU) up using the nWAKE_SIG (nFLT) pin. Further, the load current threshold that triggers the wake signal is configurable by SPI, a major benefit over hardware controlled devices since the load ECU have varied levels of wake current levels. The MCU is typically in a low power sleep mode and responds to the interrupt requests on the IO driven by the power switch device. The output voltage does not show a drop except in cases of very sudden increase in load current, in which case, the device recovers to the normal operation mode within 10s of microseconds.

The state transition diagram into and out of the low quiescent current mode (LPM) is shown in Figure 4. The transition to LPM state is controlled by SPI command and is intended for key-off or other low current states of the load. Exit from LPM to the active state can be through either SPI command or the result of a load current increase.

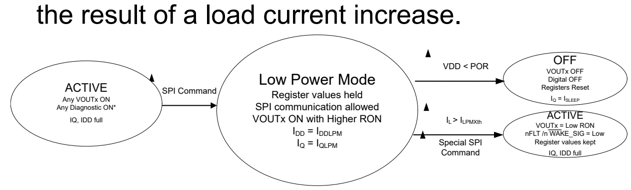

Figure 4. LPM mode state diagram

Configurable Capacitive Load Drive Mode

A key benefit of a fully software configurable device is that the device can be tailored to drive large capacitive loads seen on ECU loads. The device can be configured in the capacitive charging mode that is the best choice for the capacitance and the parallel load current draw. The device offers two options, a constant current charging mode designed for cases where there is a significant load current during charging phase or a fixed dV/dt rate charging mode that is designed for very large capacitive loads that needs to be charged with a very low charging current. In either case, the inrush current is limited to a low value during a programmable charging duration. A view of the charging and load current drive behavior is shown in Figure 5. All elements of cap charging including charging current (or dV/dt rate), charging duration and type are configurable over SPI.

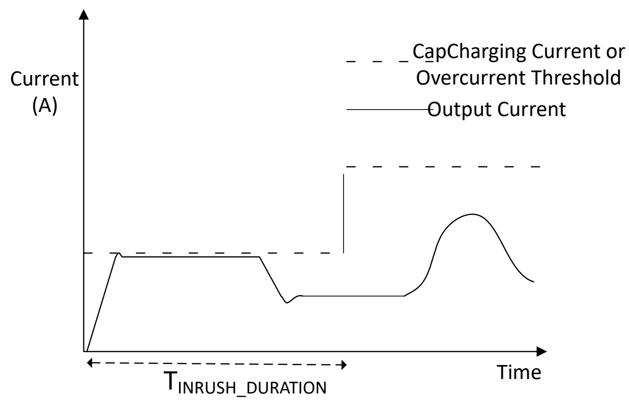

Figure 5. Configurable capacitive load drive mode

Summary

The document highlights the key benefits of the new TPS2HCS10-Q1, the first fully software configurable smart high side switch in the market. The device enables rapid platform development and improves time to market, at the same time solving a number of challenges seen in the transition from melting fuse wire harness protection to semiconductor switches, Table 1 provides an overview of the key features and the system benefits that these features provides.

Table 1. Overview of key features and system benefits of TPS2HCS10-Q1

Features	TPS2HCSxx-Q1 Integrated FET Smart eFuseHigh Side Switch	System Benefit
MCU Interface	Daisy Chainable SPI HSS	Fully software configurable (tailored to each output load). Maximum load and fault diagnostics without external components enabled by SPI
Low Quiescent current mode, System wake	Peak current capability of up to 1 A (in key-off state) and programmable wake threshold. Iq < 10µA/ch max from battery supply VBB with both channels ON	Low Iq and higher current capability with no external components or FETs. Device can transition to low power mode to reduce current consumption in ACTIVE state as well as have programmable wake thresholds. The device generates a WAKE_SIG to wake the MCU upon load current increase.
Cap charging	Slow ramp dV/dt or current limitation. cap charging modes. High (> 2mF) cap charging ability with constant current loads.	Configure loads as capacitive or actuator and associated inrush profiles. No limitation on number of cap charge cycles. No MCU overhead to enable charging mode and to time the charging mode after initial configuration
Over-current Protection	Over-current protection thresholds programmable in SPI. Dual thresholds for inrush current.	Reduce supply droop during short circuit. No external components to set the threshold.
I2t Overload Protection	Digital and programmable, no external components (lower variability)	Fully programmable fuse Time-Current curve and low variability wire protection enables lighter harness with no MCU involvement. No MCU monitoring current across multiple channels simplifies software, and full protection even with MCU failure.
Diagnostics to aid Functional Safety	Digital Current, VOUT, Vds diagnostics	VOUT/VDS ADC measurement for better load diagnostics. Very accurate low current sensing for leakage / open load diagnostics (using offset/leakage trim capability) with built-in ADC. Open-load / short to supply and FET-short failure detection with no external components.

References

- SPRY345

Trademarks

All trademarks are the property of their respective owners.

IMPORTANT NOTICE AND DISCLAIMER