Approaching a Scalable and Reliable Automotive Design with Smart Power Switching

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Background

Vehicle architecture is comprised of several components and subassemblies including control units, electronic and electromechanical sensors and actuators, and myriad loads to provide desired driving and riding functions to customers. Over the years, emphasis on meeting the minimum requirements of fuel efficiency, compliance to emissions, noise, vibration, and harshness (NVH) and safety standards has shifted to include a comfortable, interactive, and seamless driving experience with features such as voice control, smart interface integration, autonomous driving, etc. This has led to addition of various modules that serve as the "brains" for executing a specific set of functions. Managing a network with such numerous interconnections between different functions can be challenging, especially when fast communication is required between these functions. Further, the harsh automotive environment in the form of extreme temperatures, cable shorts and voltage transients can compound the challenge, and often requires high degree of robustness in these "Smart" functions. Power switching and distribution has always been an integral aspect of every function in a car. This article presents the emerging trends in automotive controls in the context of smart power switching and distribution.

Zonal vs. Domain Control Architecture

Many automotive designs today take a domain control approach to their architecture (see Figure 1a). At a high level, individual modules provide specific functionality as well as controlling the devices and sensors connected to them. However, as domains become more complex, devices and sensors may be situated further from their control module. For example, vision control functions utilize information from cameras and proximity sensors placed all around the vehicle. Connecting these devices with the vision control module requires long cables and additional interfacing. As more sensors and devices are introduced into vehicle systems, harnesses become a major weight and cost consideration.

With a zonal approach, the various "zones" or subsystems in the vehicle are connected to each other via a network (see Figure 1b). Each zone control module is responsible for driving loads and distributing power to functions specific to that zone. Thus, the harness connecting a sensor no longer has to reach across the vehicle. Rather, the sensor is connected by a much shorter cable to the respective zone control module that subsequently connects into the network.

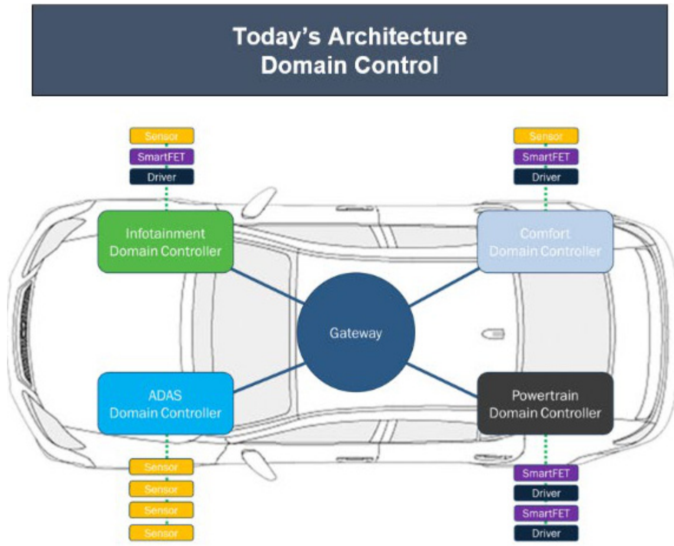

Figure 1a. With a Domain Control Approach to Automotive Design, a Module Provides Control to Devices and Sensors Needing that Specific Functionality Everywhere in the Car

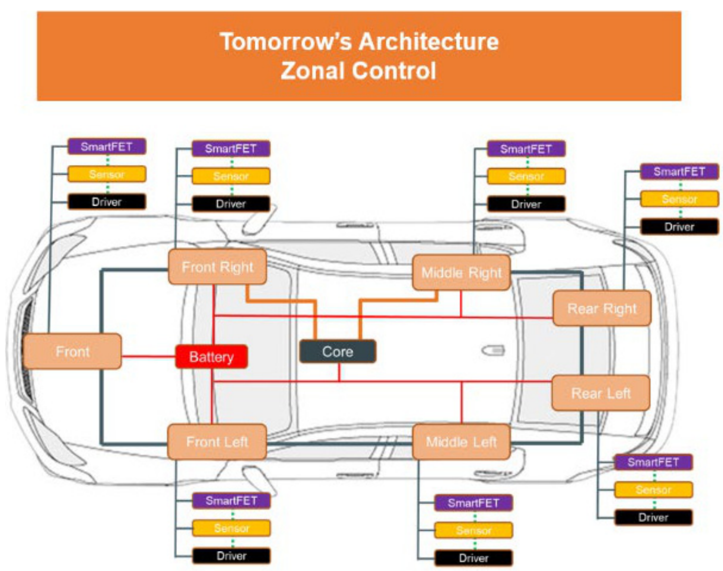

Figure 1b. With a Zonal Approach, Various Functions in Each Zone of the Vehicle Connect to a Zone Control Module, which in Turn Connect via a Network – Substantially Reducing the Required Harness

A zonal approach offers many benefits for automotive applications. High−level computing resources can be centralized and optimized across multiple functions. With centralized computing, processing resources can be easily added and shared across the entire vehicle. A faster, more advanced, in−vehicle network can produce a simpler overall architecture as well. In addition, a zonal control approach makes it easier to support software−based functionality throughout the vehicle. Further, scaling individual subsystems also becomes much less complex. The functionality of a zone can be expanded based on evolving application requirements and vehicle trims. Similarly, additional sensors and actuators can be added without requiring significant wiring. Since harnesses are currently among the heaviest and most expensive components in the vehicle, reducing harnesses lowers vehicle cost and weight.

Using a zonal approach for internal combustion vehicles also facilitates a faster transition to electric vehicles (EVs) because of similarity of design. The concerns regarding system weight and complexity cited above are amplified in EVs where the battery determines the weight and efficiency of the car, and battery life is critical in determining driving range. A zonal network can help alleviate those concerns. The electrical components serving as the core of zonal systems in combustion engines or hybrids will therefore be carried over in EV development as well and must meet requirements specific to EV environments, such as extended mission profiles.

Taking a zonal control approach requires more flexible and smarter power switching components. Traditional relays and fuses limit the efficiency that can be achieved. To provide more accurate and more efficient power management, smarter switching components are required that can collect and share relevant operating information to the control module. In addition, these components need to be self−reliant and able to diagnose and protect themselves from a wide range of power events. Various switching options available to original equipment manufacturers (OEMs) are described and compared below.

Why SmartFETs?

The variety of power switching components used in automotive applications includes relays, IGBTs, bipolar transistors, and traditional metal–oxide–semiconductor field−effect transistors (MOSFETs). MOSFET solutions have been increasingly replacing the mechanical relays and fuses for greater area efficiency and improved reliability with superior Electromagnetic Interference (EMI) and noise performance**.** They also avoid contact corrosion problems associated with relays, and unlike mechanical fuses, do not need to be replaced after overload events.

However, a traditional MOSFET is a simple switch that upon command from the controller applies or blocks power to the load regardless of whether it is safe to do so. Since MOSFETs are vulnerable to conditions such as overheating, overloading, and output short circuits, the controller must monitor and protect each MOSFET − requiring additional components and interconnects to assure safe MOSFET operation. As there can be hundreds of MOSFETs in a vehicle that need protection, this adds substantially to system complexity and cost.

Advances in power MOSFET processing technology makes it possible to integrate power switching and protection features together in an economical way. Besides less system complexity, these “smarter” power components offer greater flexibility and versatility to modern automotive designs. A SmartFET can provide switching with integrated self−diagnostics and protection circuitry in a smaller footprint while reducing the overall number of printed circuit board (PCB) traces required.

High Side vs. Low Side SmartFETs

SmartFETs or power switches can be connected to either the "low side" or the "high side" of a load. When at the low side, the load connects between +V and the switch, and the other switch terminal connects to ground. The switch is considered a low−side configuration. Alternatively, when the switch connects between +V and the load, the switch is considered a high−side configuration. An easy way to remember this is that a low−side switch connects or disconnects ground while a high−side switch connects or disconnects supply voltage.

Although SmartFETs serve both high− and low−side configurations, a particular SmartFET's characteristic is tailored to either one or the other configuration. High−side SmartFETs are relatively complex compared to their low−side counterparts, as they must include functions such as a charge pump to drive the output FET and level shifters to interface output FET control and monitoring with ground−referenced I/O terminals. Even with a complex architecture and design, high side SmartFETs are rapidly becoming the choice for switching solutions across the industry because of their superior load protection characteristics.

A SmartFET is typically housed inside a control unit. Depending upon the load type and its location in the vehicle, the cable connecting the load to the control unit could be quite long – increasing the likelihood of a short circuit to chassis ground. A low−side switch shorted to ground could be a severely stressful condition for the load, which is why switching battery with a high−side SmartFET is a safer option to protect the loads in an application. Further, with the advent of fuse replacement SmartFETs, the emphasis on high side SmartFETs has grown manifold since fuses naturally connect in a high side configuration and deliver power to the loads downstream. These high side SmartFETs paired together with a regulator and communication interface can also offer a sophisticated power management system on chip solution.

Figure 2 shows the generic block diagram for a low side SmartFET, including self−diagnostic and protection circuitry. Electrostatic discharge (ESD) protection clamps and overvoltage protection clamps limit the voltage transients and enable active clamping while switching inductive loads. Absolute and differential thermal shutdown (TSD and DTSD), and current limitation protections are also implemented.

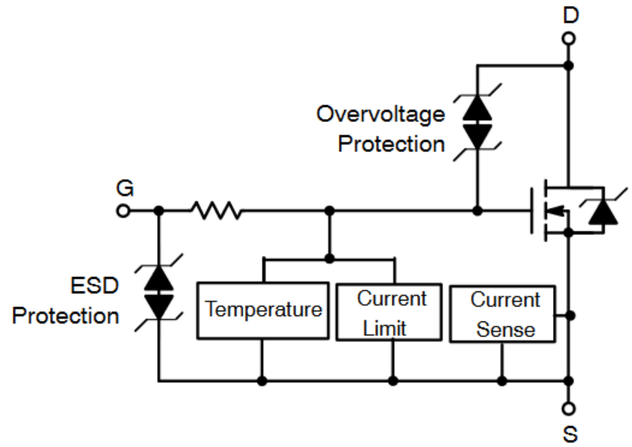

Figure 2. Generic Block Diagram of a Low Side SmartFET, Including Integrated Self−diagnostic and Protection Circuitry

Figure 3 shows the block diagram for a high side SmartFET. The high side SmartFET integrates similar protections as low side SmartFETs with the newer generation devices also offering a combined real time current sense (CS) and diagnostic reporting output.

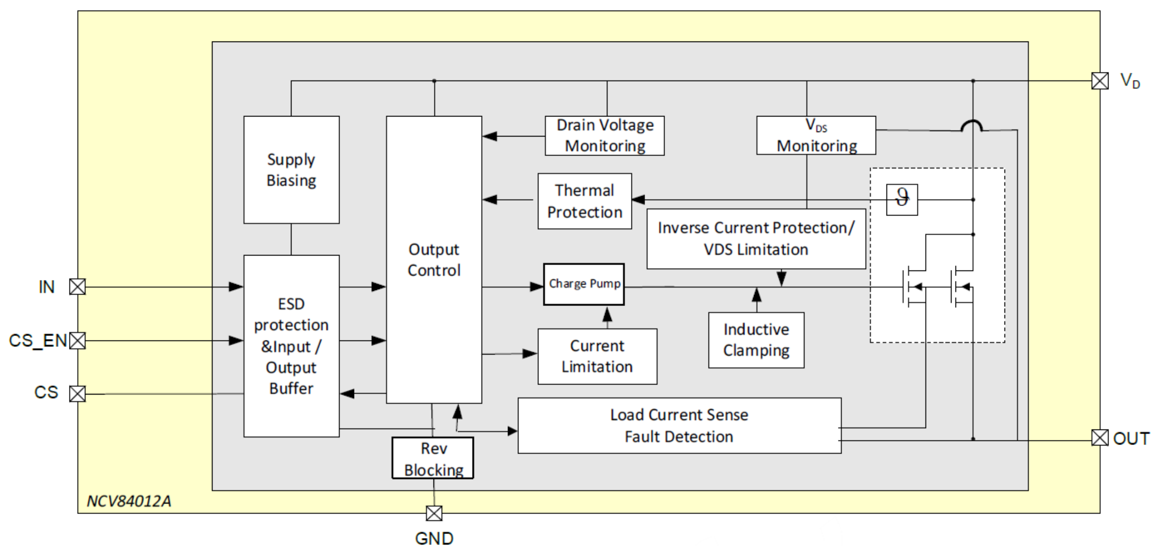

Figure 3. Generic Block Diagram of a High Side SmartFET, which Integrates Protections as Well as Diagnostic Reporting

Smart Control

SmartFETs expand upon the standard MOSFET architecture by integrating diagnostic capabilities combined with protection circuitry (i.e., a protected switch). SmartFETs can be controlled by microcontrollers (MCUs) as well as autonomously control themselves, depending upon the situation. For example, a SmartFET is able to monitor its own operation and, if necessary, shut itself down and communicate the fault to central control unit. Rather than requiring additional external monitoring and control circuitry, a SmartFET can be configured to assure it does not conduct more than allowed current by either limiting output current or shutting itself down if there is a high current event. Because monitoring is integrated, the SmartFET can react faster than an external protection circuit.

If driven by MCU, SmartFETs can be controlled by a direct control input or with the help of communication protocols such as serial peripheral interface (SPI) (Figure 4). SPI capability enables an MCU to configure the switch for different levels of operation. This means that the same device can be employed in different applications without requiring dedicated hardware to adjust the performance. Driving multiple SmartFETs in a daisy chain configuration can allow a driving interface with reduced I/O's on the MCU connector. With consolidation of many functionalities in a zone module, SPI drive capability is being actively explored by OEMs. Figure shows a configuration that does not require an MCU for control. Instead, SmartFETs are managed either using local interconnect network (LIN) or Ethernet which is able to provide dynamic protection adjustments.

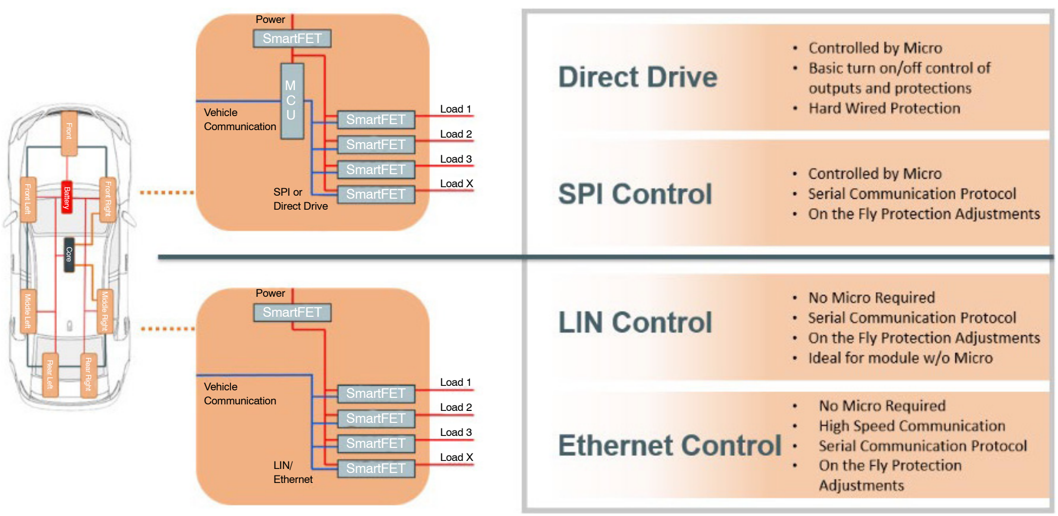

Figure 4. SmartFETs Supporting Zonal Applications

With recent improvements in design, SmartFETs are being architected to draw minimal operating current, thereby reducing the overall system leakage. This not only improves system efficiency and battery life (especially in EV's), but also enables SmartFETs to support advanced features such as sentry mode operation where just enough power is supplied in key Off mode to keep circuitry active for tasks such as periodic load checks and overnight software updates.

Circuit Protection

SmartFETs, as mentioned before, have circuitry to protect themselves, their loads, and other sensitive electronics. The automotive operating environment can be harsh, including high temperatures, high voltage, high power transients, harness or load short circuits, inductive flyback overshoots, electrostatic discharges, and other power events. To maintain reliability, power monitoring and self−protection mechanisms need to be in place to protect switches and the loads they power.

The most common fault type is a short circuit, which can take several forms. Particularly challenging is that short circuits are frequently intermittent and can occur during very brief periods, therefore causing repetitive high thermal and power “shocks” over short durations. When a short circuit occurs, the resulting high current can damage the device, harness, controller PCB and components in close proximity to the switch. A SmartFET is able to protect against a short circuit in several ways:

- The SmartFET continuously monitors the conducted current. When the internally set current threshold is exceeded, the SmartFET can regulate/limit the current, so it does not burn out traces, wires, and other components. Alternatively, it can shut the power off completely, depending upon the application and use case.
- Differential Thermal Shutdown (DTSD): The SmartFET has two temperature sensors: one in the center of the die and one at the periphery. If the die temperature rises too quickly, this could cause electro−thermal fractures on the die. Differential thermal shutdown protects the system when the current is not high enough to trigger a short circuit event but is high enough to cause a high temperature gradient.
- Thermal Shutdown (TSD): If the static temperature of the die exceeds the internally set threshold, or if the cumulative heat increases the die temperature in a continual short circuit event, the switch automatically turns itself off.

In all these protection mechanisms, the SmartFET will then wait before attempting to safely turn on again (auto−retry). In some devices, the auto−retry can continue as long as the input is enabled whereas in others, the SmartFET will disable auto−retry if the switch fails to safely turn on after a set number of attempts. The output stage will be switched off until the situation is resolved, and the MCU can safely turn the switch back on. The retry strategy for SmartFETs is described in respective product datasheets.

SmartFETs can integrate a variety of other protection mechanisms as well, including overvoltage protection, undervoltage protection by lockout, OFF−state open load and short circuit to supply detection, and output clamping for inductive load switching. onsemi SmartFETs are also optimized for active inrush handling with fast response regulation for low/med current loads and peak detect shut off for high current loads. Some SmartFETs also offer folded−back current limit to reduce power dissipation in a sustained short. Finally, with the advent of fuse replacement solutions, SmartFETs are being designed to emulate the I^2t profiles similar to thermal fuses to protect the harness and loads downstream from high power situations.

Current Sensing and Diagnostics

With the help of integrated sensors, SmartFETs can pass CS information up to the controller through a CS pin. This data updates the controller with the level of current passing through the device and also indicates if any fault event has occurred. In this way, the overall automotive system can be aware of the status of every SmartFET in the vehicle.

On the controller side, an MCU monitors sense data through an analog−to−digital converter (ADC) to obtain a digitized value of the load current. The SmartFET analog CS output is multiplexed with discrete fault indication. The common categories of faults being diagnosed include short circuit to GND/battery, open load, over−temperature, and current limit. The nominal and fault current ranges for the CS output are specified in the datasheet for the microcontroller to distinguish nominal operation from application faults.

One of the differentiating factors between SmartFETs across the industry is the accuracy of the CS output. Because this data can be useful to the controller, manufacturers are investing in developing SmartFETs that achieve greater CS accuracy. Consider, for example, a single SmartFET driving 8 strings of LEDs at 50 mA each for a total load of 400 mA. If one string fails, the load will drop to 350 mA. A highly accurate CS ratio spec can help distinguish small changes in output current levels, especially when driving light loads such as LEDs in this case. By monitoring the load current, an MCU can identify that a string has failed. Without such monitoring, the MCU will remain unaware of the failure.

CS accuracy plays an increasingly important role as vehicles transition to zonal control architectures. Because of consolidated functionality in each zone, a switch will often drive multiple loads. With access to accurate load current data, the controller can identify if a load downstream is down or not. Further, the applications in zonal architecture often require high CS ratios in SmartFETs to be able to sense higher load currents for a given CS output current.

To support even more advanced sensing capabilities in the future, OEMs can expect SmartFETs to integrate a communication interface to the controller (most likely SPI) that will enable vehicles to know more and, in turn, act more intelligently. In addition, with a SPI interface, current and voltage sense data will be available as a digital output, eliminating the need to dedicate an ADC to read this data as well as saving the space for external components on the board.

Integration = Reliability + Simplicity

Conclusion

As a market leader in power electronics, onsemi is committed to providing the technology OEMs need to design and manufacture efficient and reliable vehicles. A key part of our vision is to keep **onsemi**'s supply chain focused on enabling OEMs to build a sustainable technology.

The shift from domain control to zonal control has led to a consolidation of functionality in automotive applications. A consequence of this consolidation is the need for more power to each zone, where it is distributed appropriately. To help lower harness costs while reducing vehicle weight and increasing reliability, OEMs need smart power switching components that can reliably deliver power, reduce design complexity, and simplify scaling as automobiles continue their transition to fully electric vehicles.

SmartFETs change how vehicles deliver power and protect their electrical infrastructure. With the integration of accurate diagnostic functionality and protection circuitry in the switch itself, SmartFETs offer self−reliant power switching that reduces system complexity, simplifies design, reduces component count, shrinks electronic footprint, and eliminates redundant cabling all while increasing reliability and lowering total cost of ownership. With active control circuitry constantly monitoring output current and device temperature, combined with passive protection against voltage transient and other power events, SmartFETs are ideal for many automotive applications.

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