How safety requirements for autonomous vehicles will reinvent fuse and relay boxes in automotive power distribution

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Abstract

Open up the bonnet of any modern automobile and many of us would be hard-pressed to find anything that we could fix ourselves. With pipes and cables almost artistically integra-ted into the engine bay, and sleek plastic covers fitted everywhere, there is very little that can still be recognised, let alone repaired. Perhaps the only location where we feel comfortable is the “fuse box”, or power distribution centre (PDC), housing the fuses and relays. However, with the introduction of electrical drivetrains and ever more assistive and autonomous driving features, even this last bastion of self-repair is likely to disappear in future vehicles. In this white paper we review how high-side switches, such as those from Infineon’s PROFET™ portfolio, are driving the next generation of automotive power distribution architectures.

New features drive new considerations

Advanced Driver Assistance Systems (ADAS) and autonomous driving (AD) require further thought when undertaking system risk assessments in today’s vehicle designs due to their increased complexity (figure 1). Often, under failure conditions, they typically fall into a fail-safe state. This means that, rather than preventing failure, they are designed to enter a state that attenuates the consequences of that failure to reduce or eliminate any potential harm. A fuse blowing is one simple method to ensure an electrical system can fail safely. In this case, to avoid a high current draw from the battery causing the electrical cabling from overheating or even igniting.

Due to the risks associated with some ADAS and AD functionality, a fail-operational approach will be needed. This will require that the system affected can continue to function either fully, or with degraded capability. Instead, systems will require more granular control of power delivery paths and the implementation of redundancy for critical systems. This is likely to include fall-back actuators as well as alternative battery power sources, should the primary ones fail. For example, if power supply failure should occur, power control for a motor may be switched to an alternate ECU, while energy is sourced from an alternative battery.

Obviously, such an electrical system cannot be protected by simple sacrificial devices such as fuses.

Approaching a smart power distribution concept

It quickly becomes clear that distributing power through a centralised relay and fuse box, whose position is determined only for the convenience of maintenance, is disadvantageous for future E/E Architectures of the vehicle. Additionally, to provide more granularity for implementing electrically isolatable islands of functionality, the number of relays required will increase.

Beyond the issue of being sacrificial, fuses are also relatively slow, taking up to 100ms to remove the power to a failing electrical circuit. They also have to be replaced once blown. Relays too, being electromechanical devices, also have their disadvantages. Socketed devices suffer from galvanic corrosion over time, and they are limited to around 100k switching cycles. They can also develop issues with their contacts due to arching, or develop issues under dry switching conditions. Relays also require an additional driver circuit in order for devices such as microcontrollers (MCU) to control them. Together the fuse, relay and driver circuit combination provide no diagnostic functionality and, usually dissipating around 5W of energy, are wasteful and contribute to higher CO_2 emissions. Finally, pulse-width modulation (PWM) of power to control loads, such as electrical heaters, is not possible.
The E/E architecture of most OEMs is moving toward an approach that has an increased number of power domains, which would inevitably require more fuse/relay combinations to provide the necessary protection. Retaining today's current approach, this would require a very large central fuse box or many smaller fuse boxes spread around the vehicle. However, access to these fuse boxes would still need to be guaranteed so that fuses and relays can be replaced over the lifetime of the vehicle. Bearing in mind the weakness of this approach already highlighted, a more modern approach that can also integrate some additional intelligence (power and condition monitoring) is required.

To combat some of these challenges, power distribution needs to move from a centralised to a decentralised approach (figure 1). This will bring power switching and protection circuitry closer to the point of the consumption. With PDCs spread around the vehicle in locations with poor access, replaceable components such as fuses and relays make way for silicon devices. Silicon switches do not wear like the contacts of a relay, and are not susceptible to issues caused by dust, vibration, and other environmental factors. Additionally, power devices are capable of handling high surge currents while also detecting overcurrent scenarios, thus integrating the protection feature of the sacrificial fuse in a sub-millisecond timeframe.

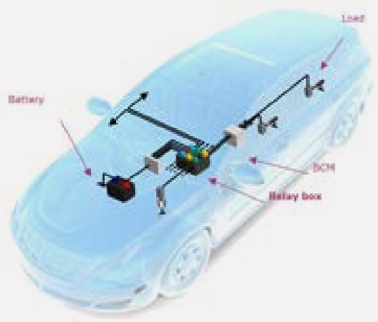
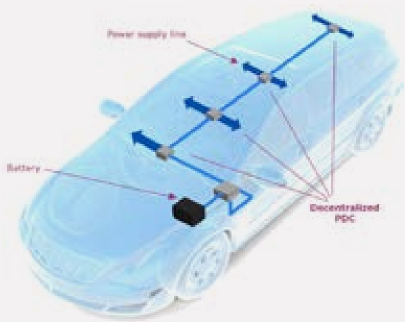
Classic power distribution	Smart power distribution
	
Central relay and fuse box.	**Multiple** small **power distribution centers** connected by LIN or CAN.
Accessible location to exchange blown fuses.	**Reduced wire harness** optimizes system cost and weight.
Vulnerable to mechanical wear, dust, shock, vibration and aging.	**Enhanced diagnostics, protection** and **EMC robustness.**

Figure 1: Future power distribution is moving away from centralised approach to multiple decentralised PDCs.

To provide the desired granularity of control and diagnostic feedback, the PDCs are connected via a communication network that integrates with the vehicle's other systems. Even if there are multiple supplies, such as 12V and 48V, in addition to the electric vehicle's (EV) motive power source, a central ECU can monitor power and control its distribution as is demanded by the vehicles systems, or in order to compensate for the impact of a system failure.

Silicon alternatives to fuses and relays

MOSFET technology is an obvious choice as a replacement for the relay-fuse combination. However, this simple silicon device requires further circuitry to implement the full feature set of the electromechanical solution it is replacing. Recognising the market need for a fully integrated silicon solution, Infineon has developed its PROFET™ (PROtected mosFET) smart and protected high-side switch family (figure 3). They dissipate a significantly lower power than the driver/fuse/relay circuit they replace (figure 2), do not suffer from contact bounce at switch on, and the controlled switching generates minimal EMI. Dry switching is not a concern for PROFET™ devices and they are unaffected by the arcing that occurs in relays. Finally, they can endure more than 1015 activations over their lifetime, significantly more than the hundreds of thousands electrical endurance switching of a relay.

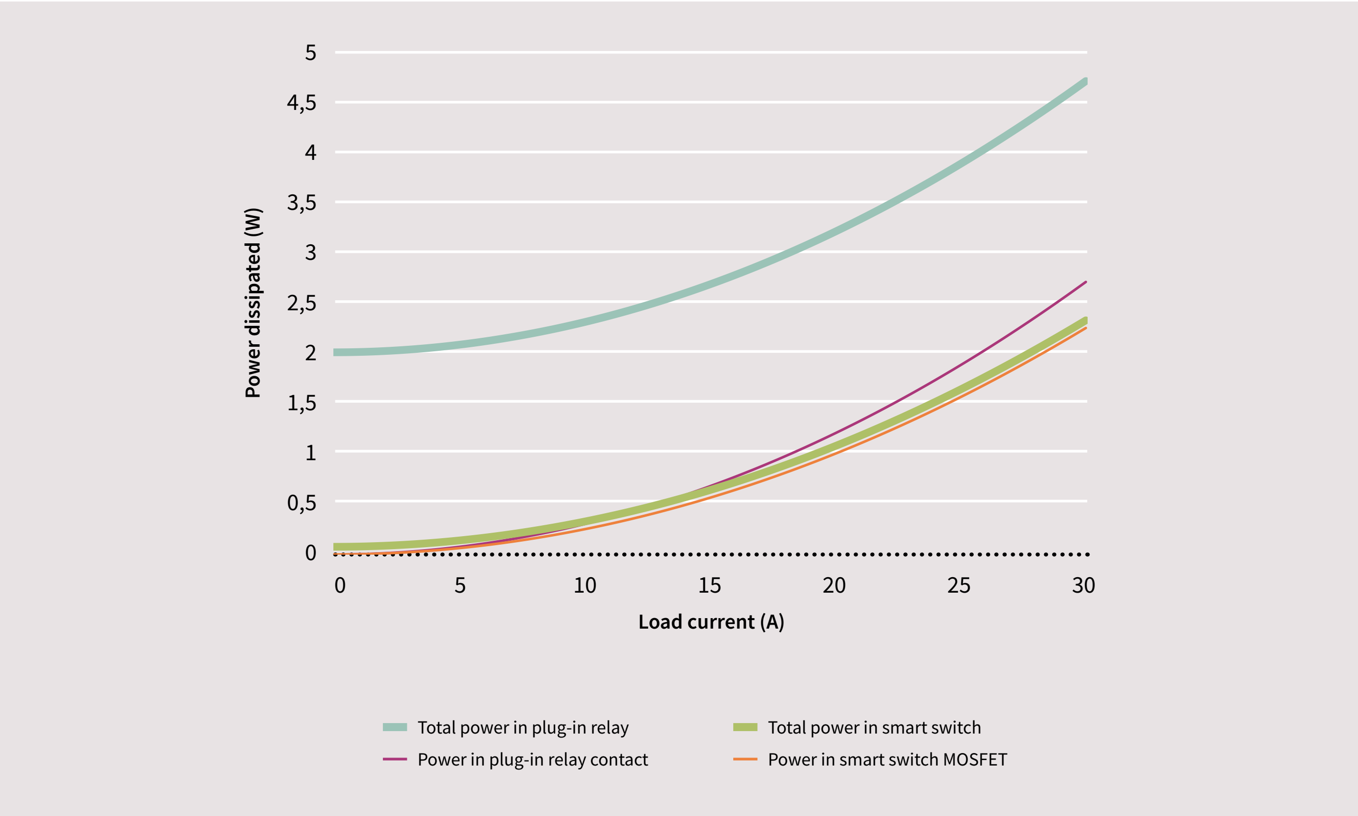


Figure 2: PROFET™ devices offer a significant drop in power dissipation compared to the plug-in relays they replace.

The devices are automotive qualified and capable of controlling resistive, capacitive and inductive loads. Split into three distinct families, there are devices available to address all body applications within the vehicle. Differentiating themselves in their on-state resistance (RDS(ON)), they are suitable for switching loads from a few mA up to 40A DC. Reflecting the challenges of the environment they are deployed in, they integrate wide ranging protection features including thermal shutdown, short circuit protection and reverse battery protection, to name but a few. These features are also integrated into the diagnosis functionality, allowing a host microcontroller (MCU) to evaluate the status of the load and share this with a central ECU, or even shut down power to the load.

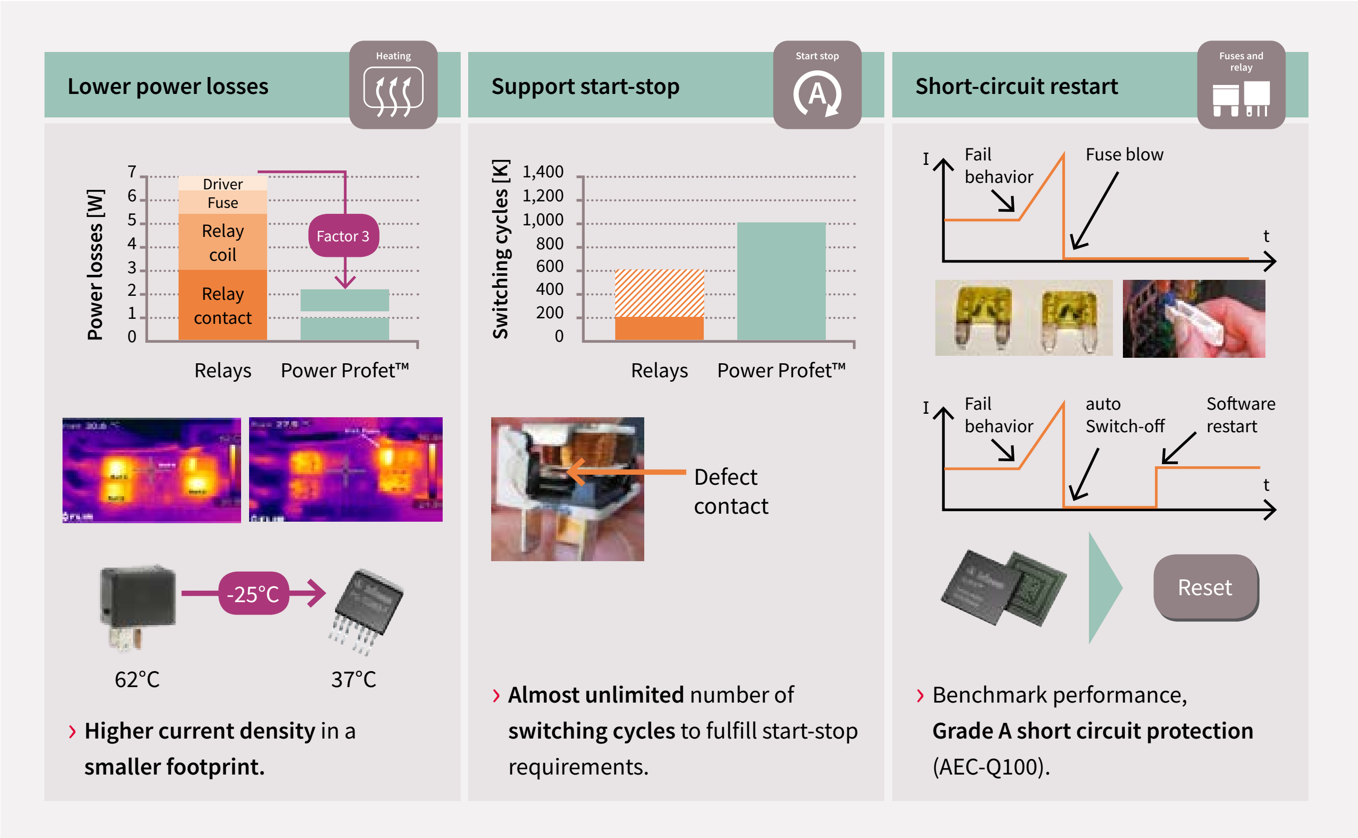


Figure 3: Compared to the classic fuse/relay combo, PROFET™ devices reduce power consumption, support high switching cycles, and are resettable.

The first in the family are the Power PROFET™3. These single output devices provide the same control and protection offering as the fuse/relay combo they replace, coupled with the diagnostic intelligence that an integrated circuit can provide. The protection concept with its current trip and latch behaviour replicates a fuse in short circuit scenarios, while also providing thermal protection.

To manage the challenges of electromagnetic compatibility (EMC), provision is made for slew-rate control. This ensures an optimised trade-off between switching losses and RF emissions when controlling high-current loads.

The BTS50010-1TAD can switch loads of up to 40 A with a current trip set at 150 A. Compared to the driver circuit and losses associated with a fuse and relay, the Power PROFET™ can be three times more power efficient. Additionally, it offers significantly more features while offering a compelling cost-down at the system level (figure 4).

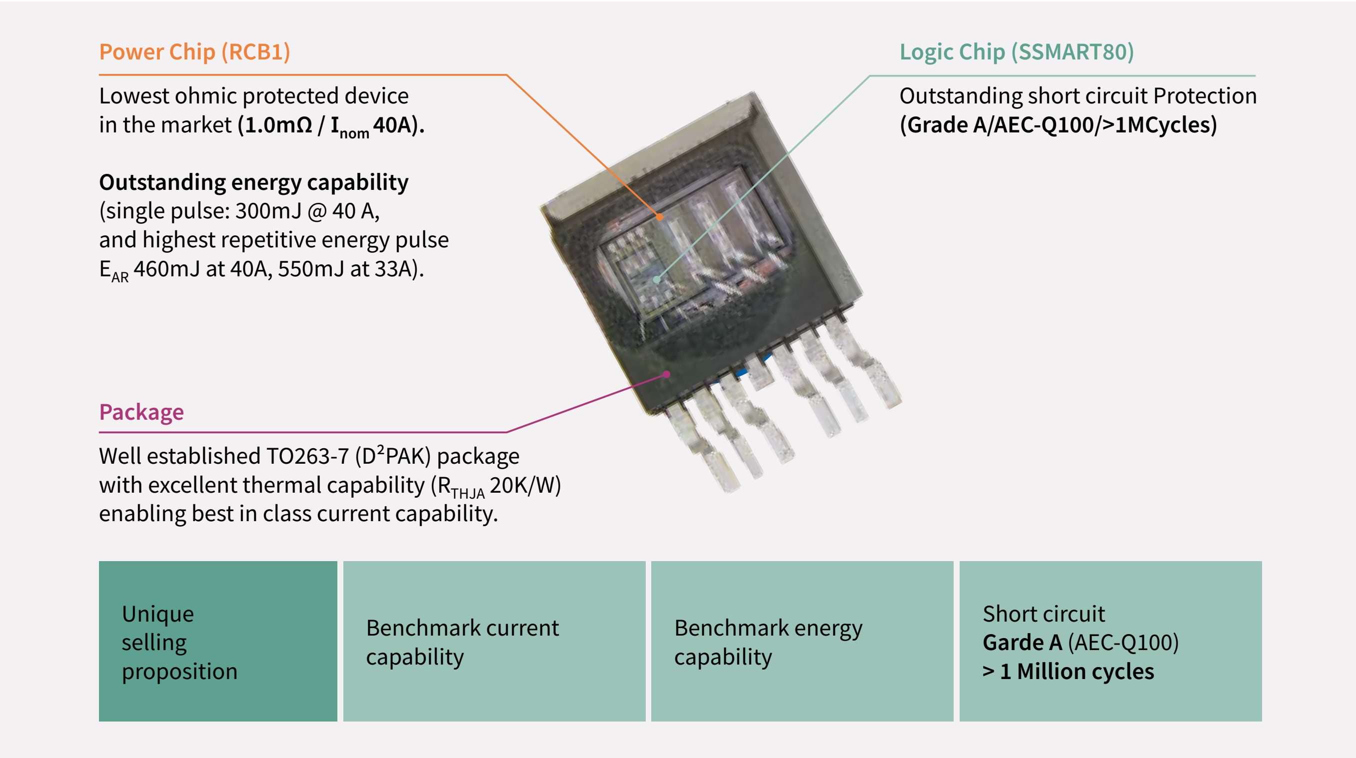


Figure 4: The Power PROFET™ series complements todays start-stop CO2 saving features with their outstanding energy capability and PWM support.

The next family, the PROFET™+22, are available as single and dual channel devices supporting applications with a current draw of up to 20 A (figure 5). Along with protection against electrostatic discharge (ESD), the devices also integrate a mechanism for “loss of ground” situations. Supporting in-rush currents of up to 122 A, the PROFET™+2 series delivers current sense measurements to a host MCU up to the current trip point of the chosen device. This is implemented using a current mirror approach and can be determined in software through the use of the stated Kilis factor. The accuracy of the current sense can, after calibration in conjunction with the selected load, reach +/-5%, down from +/-8% prior to calibration.

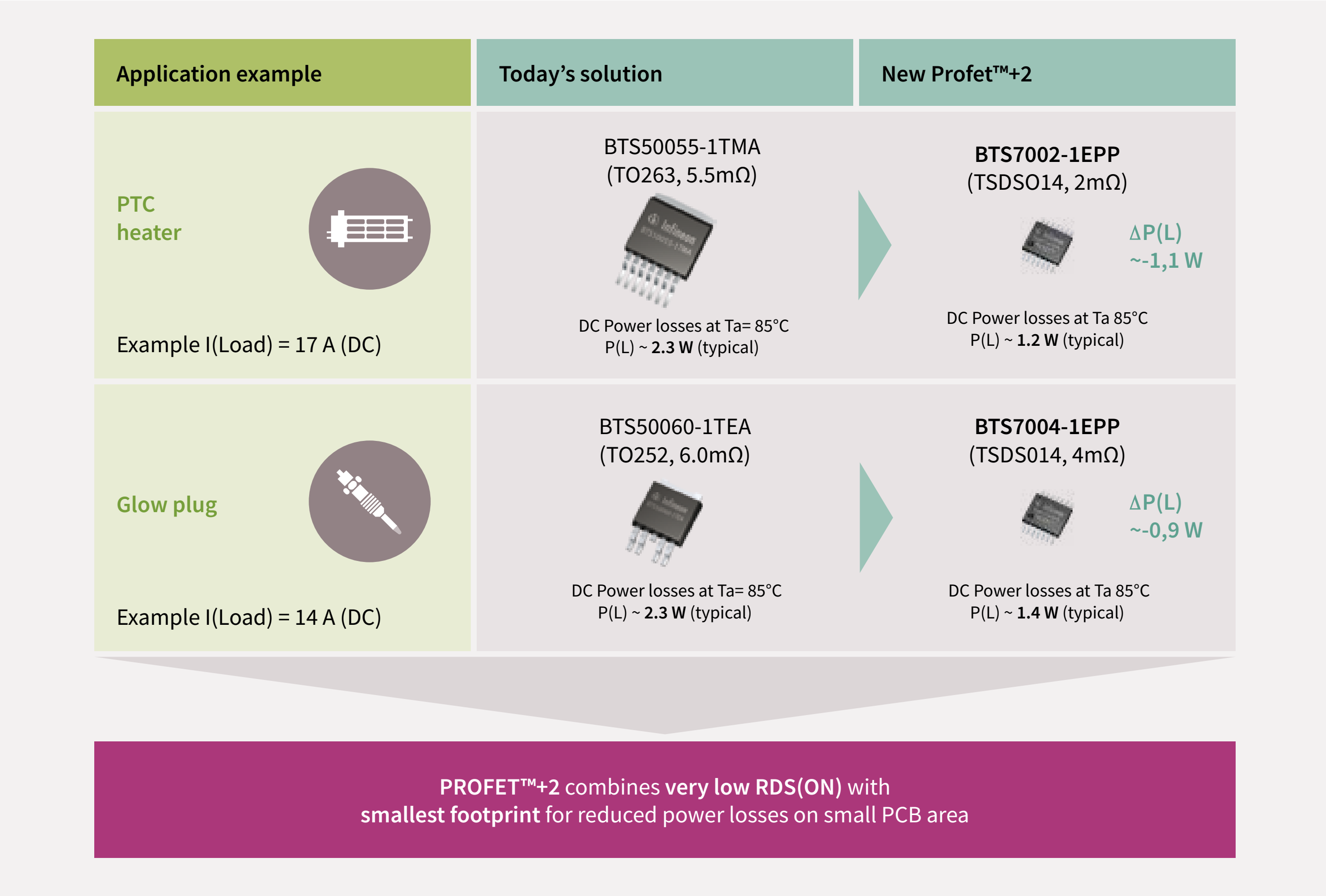


Figure 5: PROFET™+2 high-side switches provide minimal losses as relay replacements, when compared to previous high current PROFET solutions, without the need for a bulky heatsink.

The final family are the SPOC™+21 SPI power controllers (figure 7). Offering between four and six channels in an innovative TSDSO-24 package, these multi-channel high-side switches are ideal for body applications both inside and on the exterior of the vehicle. The SPI interface allows a single device or multiple daisy-chained devices to be linked to an MCU. The output loads can then be controlled via the SPI interface or via the input control pins.

The SPI interface can also be used to switch between multiple loads in order that the host MCU can perform current measurements. In the event of a system failure that results in SPI communication to cease operation, the SPOC™+2 provides a fall-back "limp home" mode. In this mode the outputs can still be controlled via the control pins with the majority of the safety provisions operational, but without the support of the diagnostic features.

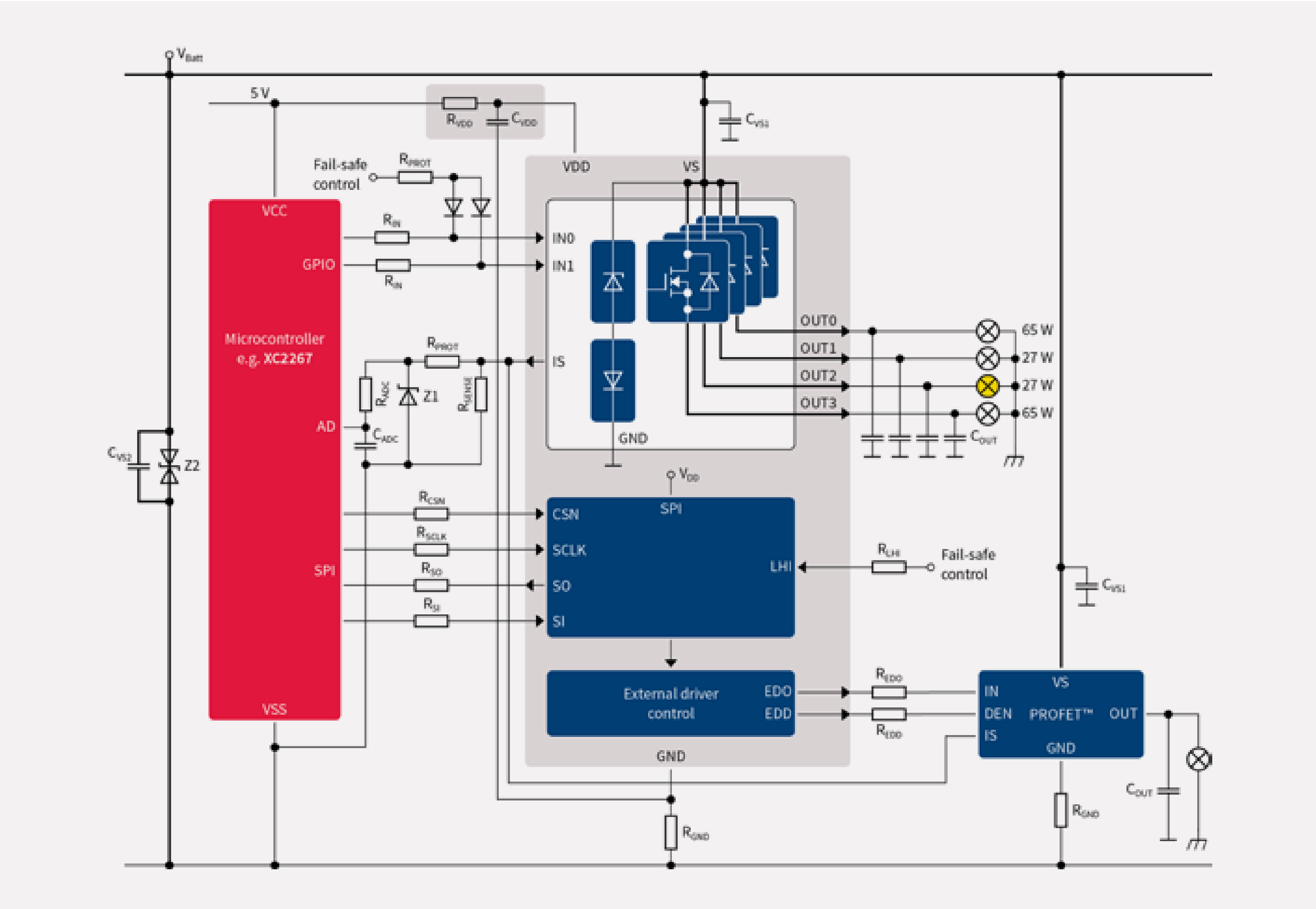


Figure 6: SPOC™+2 multi-channel high-side switches provide both control and diagnostic capability via SPI.

The future of power distribution in the vehicle

Future power distribution in the vehicle will require more granular control and monitoring capability, along with the option to switch to alternative power sources under failure conditions. The PDC example shown in figure 8 replaces the typical fuse and relay components entirely with semiconductor alternatives, and is designed to meet the needs of a vehicle with Level 3 ADAS features.

The key focus here is to ensure that the safety critical function of ADAS features, such as braking, steering and sensors (LiDAR, Radar, etc), plus their computing systems, are always safely powered. To attain this goal, a Fail Operation island has been created that can source its power from either the 12V battery or via a DCDC converter providing 12V from the 48V battery. A combination of power MOSFETs and AUIR3241S gate drivers are used to implement an OR function, ensuring that power from at least one of the power sources is always available. This approach guarantees that the Safe Operational island is always supplied. PROFET solutions monitor the current drawn by each load, enabling built-in safety diagnostics and the optional implementation of wire protection to avoid overheating in the case of failure of a load.

There are two further power islands for loads that only require a fail-safe supply. For loads that are insensitive to battery polarity, PROFETs provide a direct connection to the 12V battery. This covers systems such as the horn, PTC heaters, windshield defrosters and similar loads.
For loads that are sensitive to battery polarity a reverse battery polarity function is integrated using a power MOSFET and AUIR3241S gate driver. This protects the solenoid starter, engine cooling fan, AC clutch, and similar systems that are controlled via PROFET solutions. For safety reasons the PROFET supplying the solenoid starter is supplied via a redundant transistor to ensure that the load can be disconnected even if the PROFET switch should be damaged and falls into a short-circuit state.

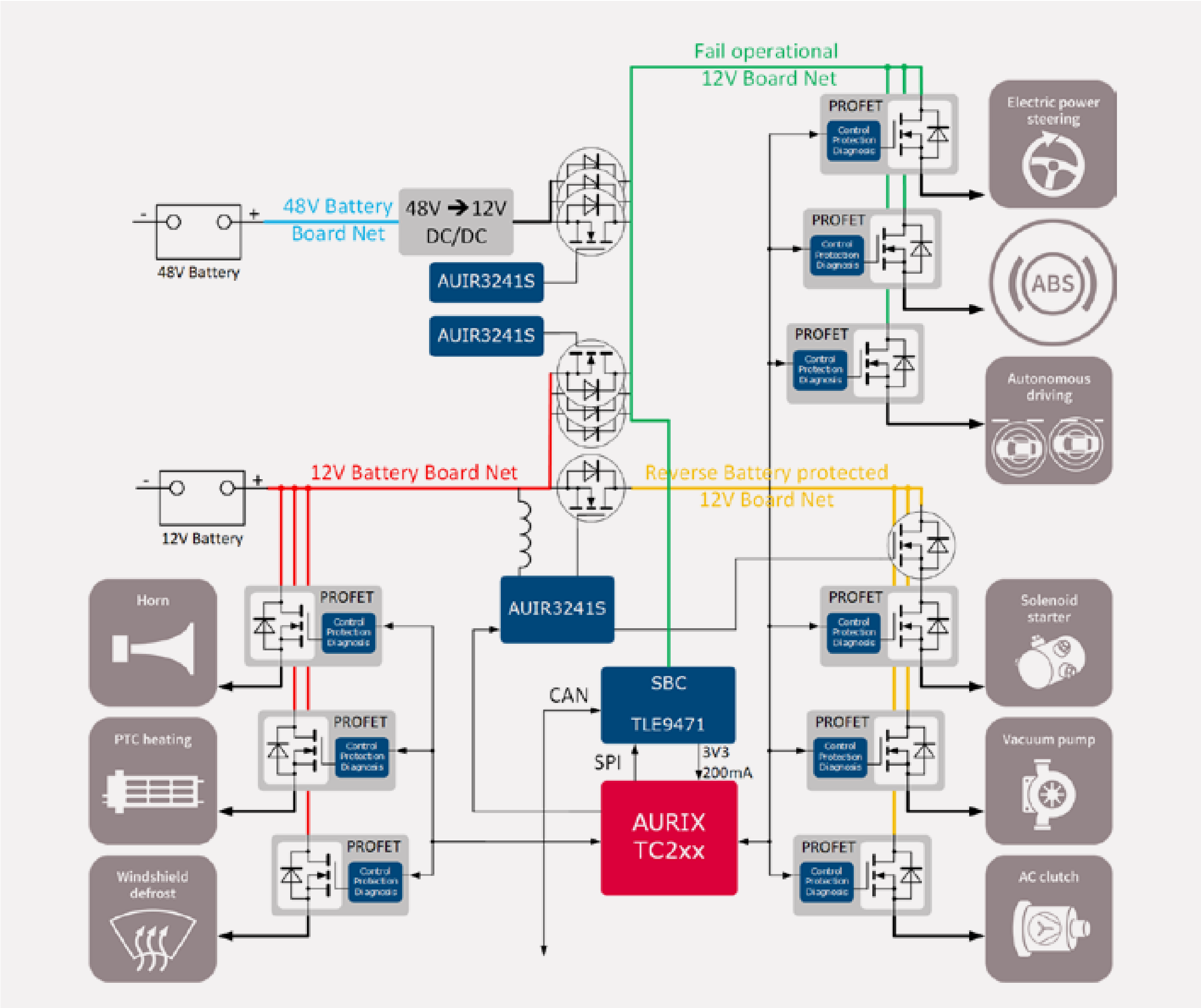


Figure 7: Power distribution in the vehicle will be split into different power domains, along with back-up power support for safety critical systems

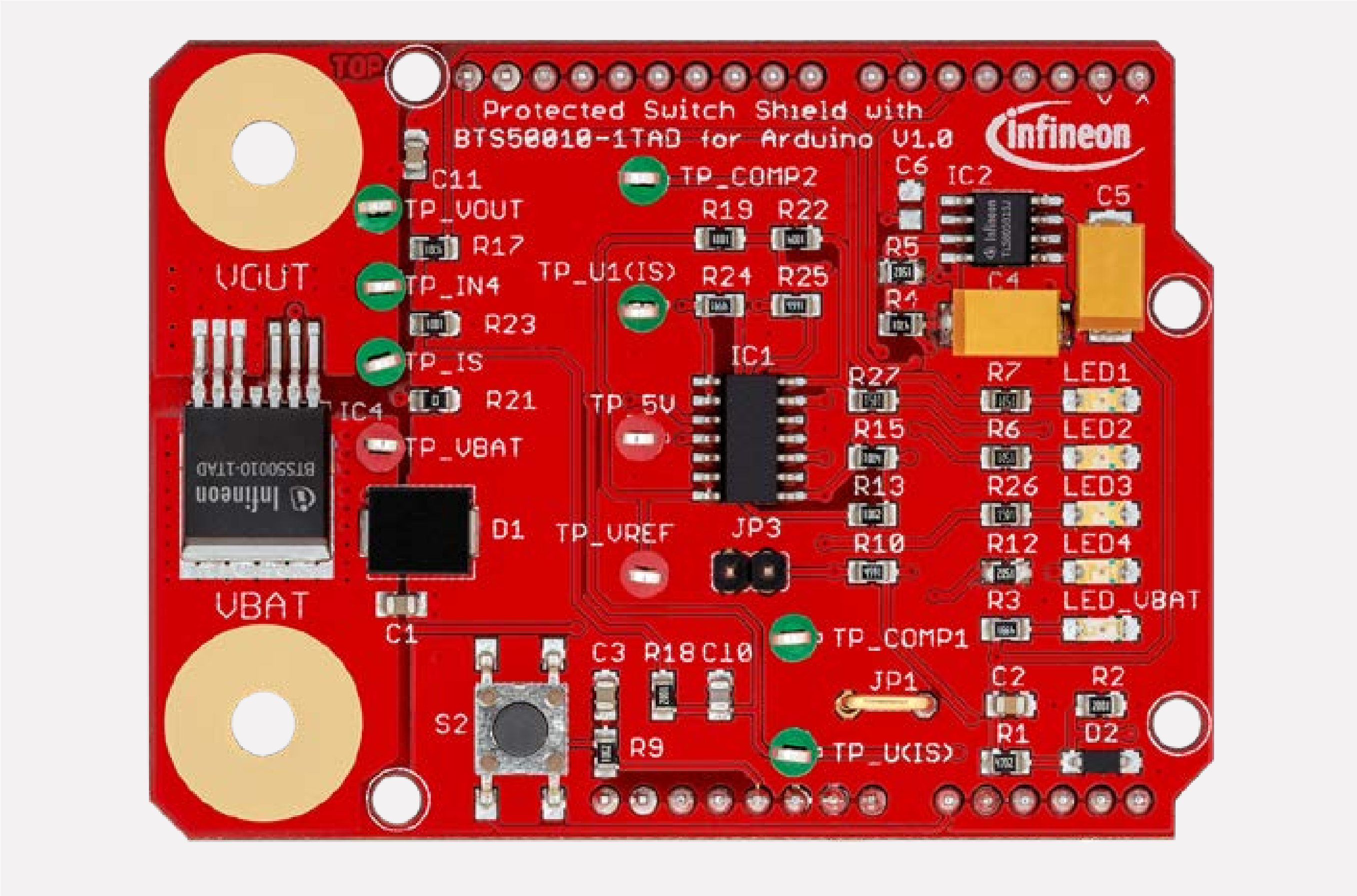


Figure 8: Evaluation of devices such as the Power PROFET™ are simplified with the availability of Arduino shields.

Evaluation of these high-side switching solutions is simplified with a range of development boards on offer. The SHIELD_BTS50010-1TAD6 is one such option designed to function with the Arduino form factor development boards, enabling a fast and simple appraisal (figure 9).

Summary

With much of vehicle electronics having moved to silicon-based alternatives, it is time for power distribution to move on as well. Future drivetrains, safety considerations in autonomous driving mode, and remote diagnostic support demand a move away from the traditional fuse/relay combo. The automotive industry, and consumers, not only benefit from associated weight savings in the cable loom and improved failure analysis. The move to silicon high-side switches from the PROFET™ family delivers significant energy and cost savings over the vehicle's lifetime too.

Notes and temporary references

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