



How semiconductor solutions address safety requirements of future power distribution networks in autonomous vehicles

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 integrated into the engine bay, and sleek plastic covers fitted everywhere, there is very little that can still be recognized, yet alone repaired. Perhaps the only location where we feel comfortable is the “fuse box”, or power distribution center (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.

Get to know Infineon's
high-side switch portfolio



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1. New architecture requirements drive new use cases

Advanced Driver Assistance Systems (ADAS) and autonomous driving (AD) require further thoughts when undertaking system risk assessments in today's vehicle designs due to their increased complexity (figure 1). Under failure conditions, the ADAS systems 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 the AD functionality, a fail-operational approach will now be needed. This will require that the system affected can continue to function either fully, or with degraded capability.

As a result, systems will require more diagnostics 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, if the primary ones fail. For example, if power supply failure occurs, power control for a motor may be switched to an alternate ECU, while energy is sourced from an alternative battery. This needs to be assured within fast reaction time, in order to protect safety critical functionalities.

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

2. 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 switched loads required will increase which requires fast fault detection.

Beyond the issue of being sacrificial, fuses are also relatively slow, taking more than 10 ms up to several 100 ms to cut off the power to a failing electrical circuit. They also have to be replaced once blown. Relays, being electromechanical devices, also have their disadvantages. Socketed devices suffer from contact corrosion over time, may develop issues with their contacts due to arcing or develop issues under dry switching conditions. Furthermore, their lifecycle is limited to around 100k switching cycles. Relays also require an additional driver circuit so that devices such as microcontrollers (MCU) are able to control them. Together the fuse, relay and driver circuit combination does not provide diagnostic functionality and, dissipating up to 4.5 W of energy, are wasteful and contribute to higher CO₂ 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 towards an approach that has an increased number of power domains within zone architectures which would inevitably require more fuse/relay combinations to provide the necessary protection. Retaining today's approach, this would require a very large central fuse box or many smaller fuse boxes spread around the vehicle. However, these would still need to be accessible so that fuses and relays can be replaced over the lifetime of the vehicle. Bearing in mind these weaknesses, a more modern approach that can also integrate some additional intelligence (power and condition monitoring) is required.

To address 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 load. 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.

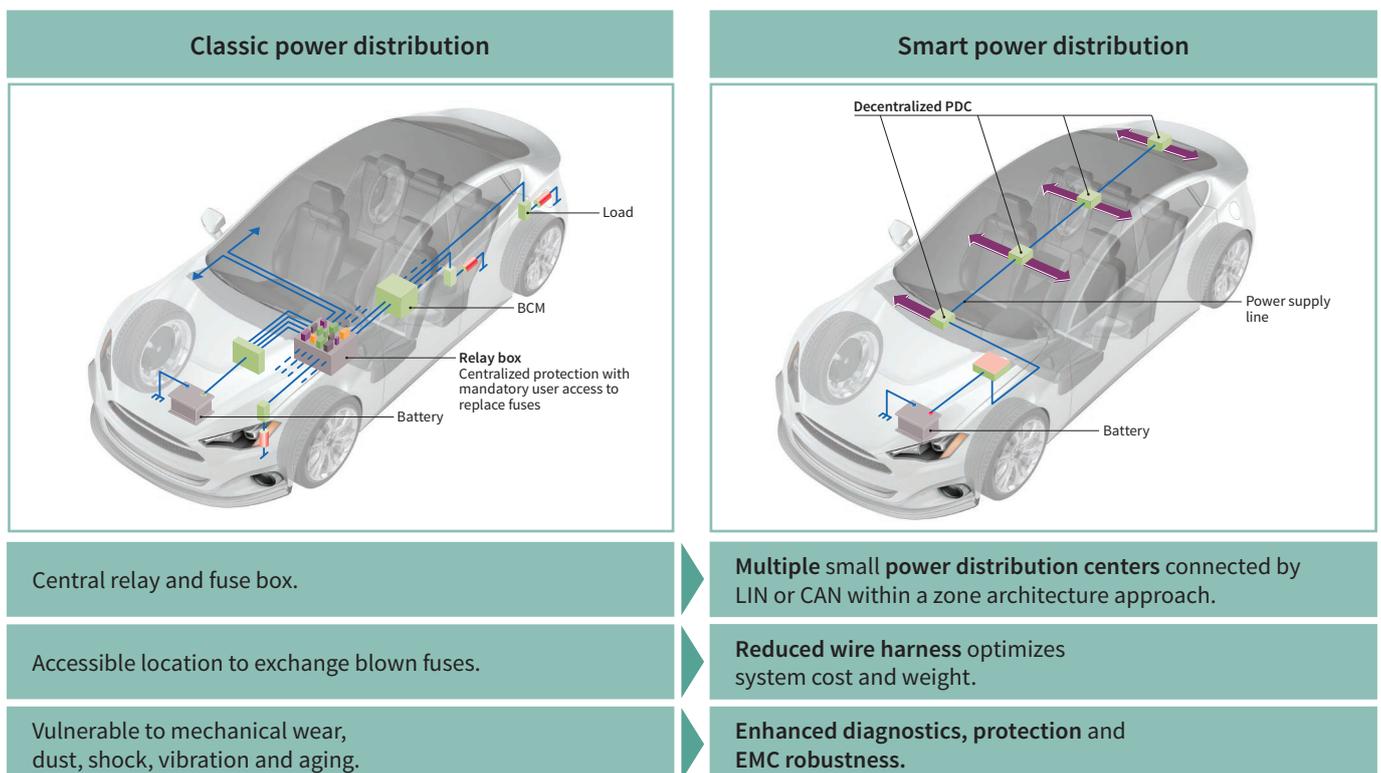


Figure 1: Future power distribution is moving away from centralised approach to multiple decentralised PDCs.

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 12 V and 48 V,

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.

3. 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. Recognizing the market need for a fully integrated silicon solution, Infineon is working on integrated solutions to address currents higher than 40 A using gate drivers and MOSFETs, so that even higher currents will be addressable with semiconductors. For solutions under 40 A, Infineon has developed its [PROFET™ \(PROtected mosFET\) smart and protected high-side power switch family](#). 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 up to 10 million activations over their lifetime, significantly more than the hundreds of thousands electrical endurance switching of a relay.

The PROFET™ devices are automotive qualified and capable of controlling resistive, capacitive and inductive loads. Split into three distinct families (figure 3), there are devices available to address most of the automotive applications. Differentiating themselves in their on-state resistance ($R_{DS(ON)}$), they are suitable for switching loads from a few mA up to 40 A 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.

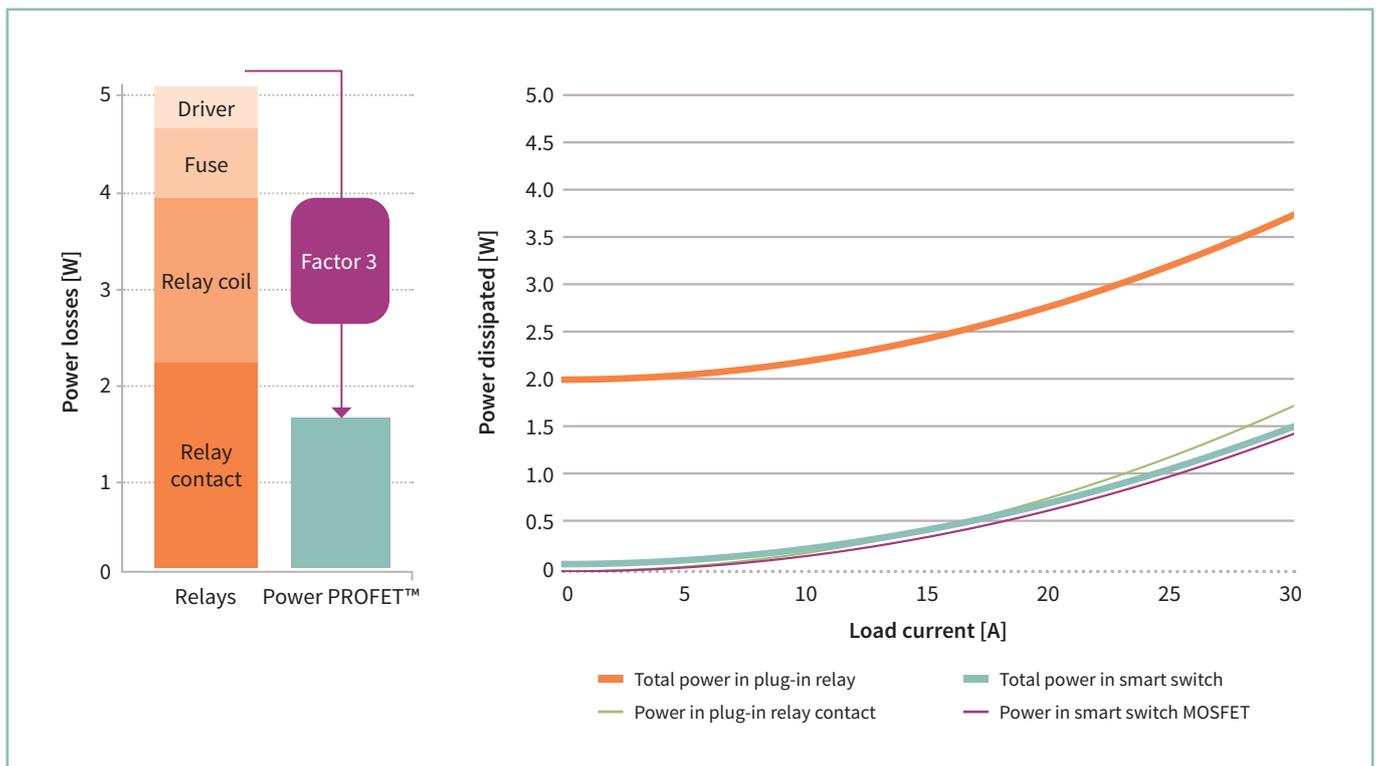


Figure 2: PROFET™ devices offer a significant drop in power dissipation compared to the plug-in relays they replace.

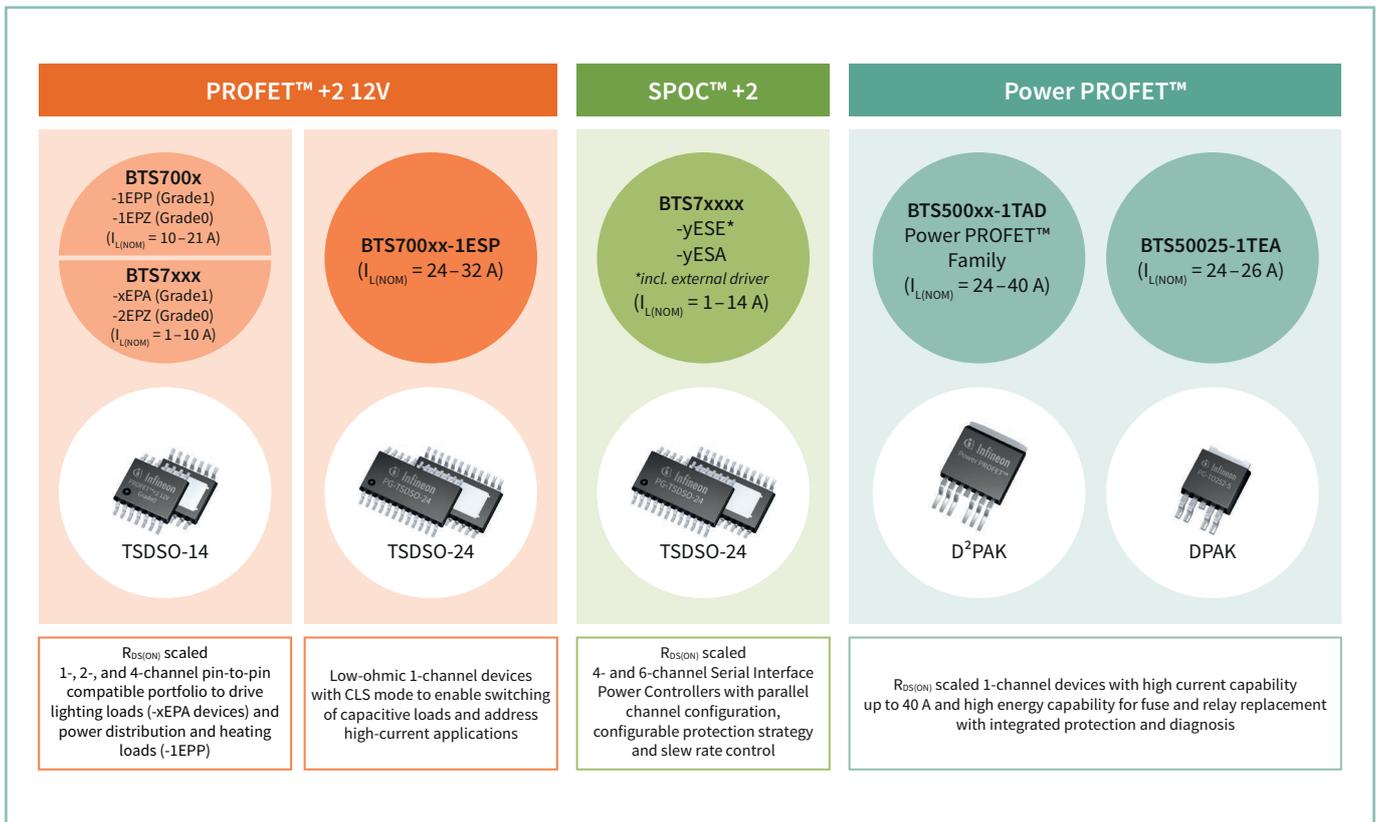


Figure 3: Infineon offers a broad portfolio of intelligent high-side power switches addressing loads from 1 A up to 40 A.

The first family, the [PROFET™ +2 12V²](#), are available as single, dual and quad channel devices supporting applications with a current draw of up to 32 A. 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 187 A, the PROFET™ +2 12V 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 k_{ILIS} factor. After calibration in conjunction with the selected load, the accuracy of the current sense can reach below 4%. In addition to the automotive qualified devices according to AEC-Q100 Grade1, switches qualified according to

AEC-Q100 Grade0 provide extended thermal budget and can withstand a junction temperature of up to 175°C. The latest released PROFET™ +2 12V – ESP devices support currents up to 32 A and provide the new feature called Capacitive Load Switching mode. The CLS mode enables switching of big input capacitors in a safe operating area and is activated by an PWM signal of, for example, 30 kHz applied to the input pin and a duty cycle of 50%. In this condition, slew rate is reduced, T_J (DYN) protection is set to a lower value and restart is activated. The capacitor gets charged by pumping and overtemperature protection remains untriggered (figure 4). In near future, PROFET™ +2 12V devices will also be ISO26262-ready, starting from end of 2022.

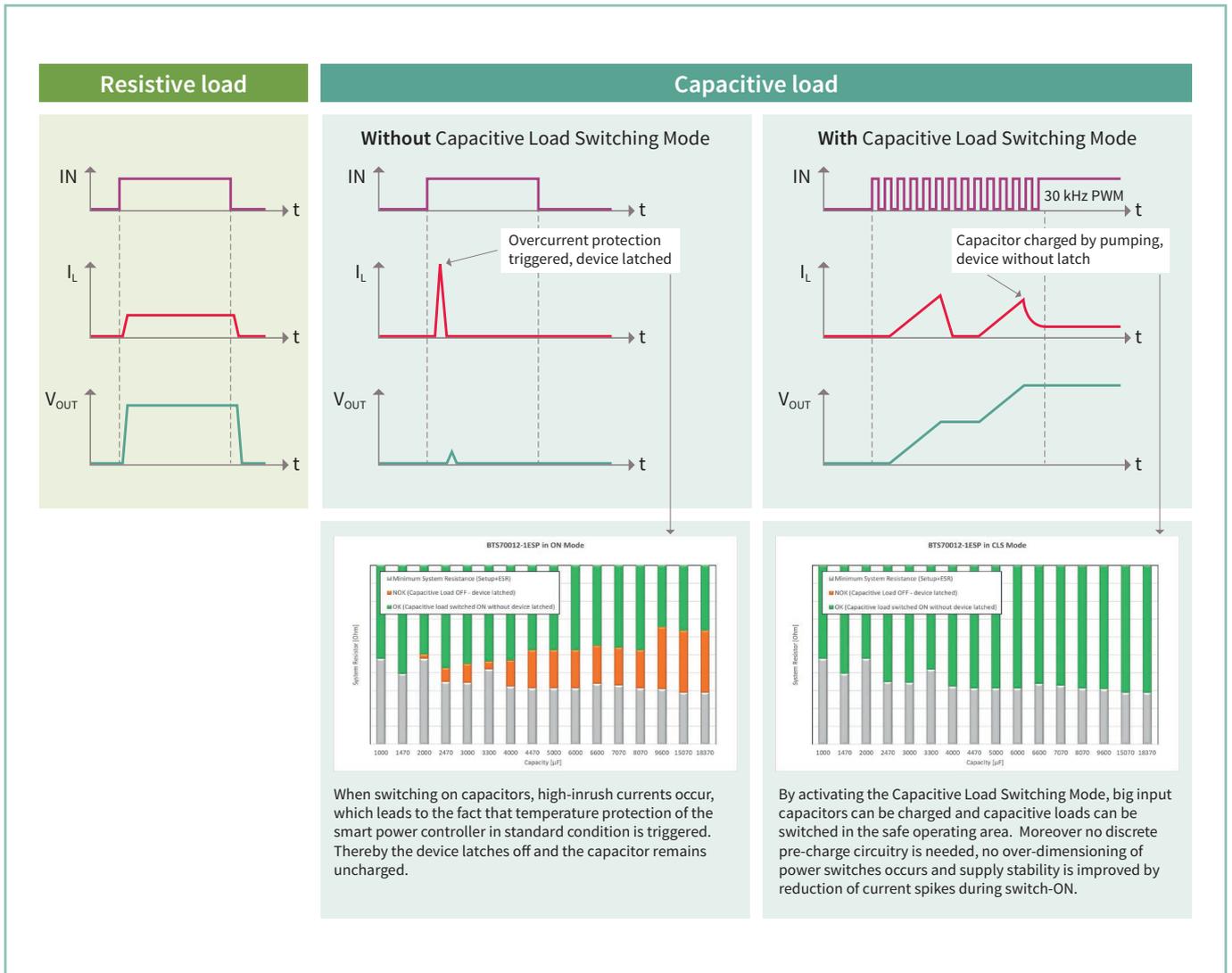


Figure 4: The newly released PROFET™ +2 12V products BTS70012-1ESP, BTS70015-1ESP & BTS70020-1ESP are equipped with the latest feature, called **Capacitive Load Switching Mode**

The [SPOC™ +2](#)¹ serial interface power controller family consists of different four- and one six-channel device(s) in an innovative TSDSO-24 package (figure 5). These smart power switches with protection and diagnosis features are ideal for body applications addressing a nominal current range between 1.5 A and 7 A in single channel mode and up to 14 A via channel parallelization. SPOC™ +2 offers a high flexibility with configurable features like slew rate control and intelligent restart strategy to support power distribution. Furthermore the SPI interface allows to connect multiple devices via daisy-chain configuration to reduce the amount of necessary GPIOs and therefore contributes to save board space. In the event of a system

failure that forces SPI communication to stop operating, the SPOC™ +2 provides “limp home mode” as a fallback. In this mode the output pins can still be controlled via the input pins which supports fail safe operation. Although the SPI control is stopped, diagnosis feedback as well as input status can still be provided. Additionally, ISO 26262-ready documentation enables the use of standard AEC-Q100 developed products in safety related applications. In addition to our SPOC™ +2 devices, a Safety Application Note is available for download. It delivers the necessary documentation like FIT rates, failure mode distribution and FFM to apply ISO 26262-8:2018, Clause 13 in order to support functional safety assessment on system level.

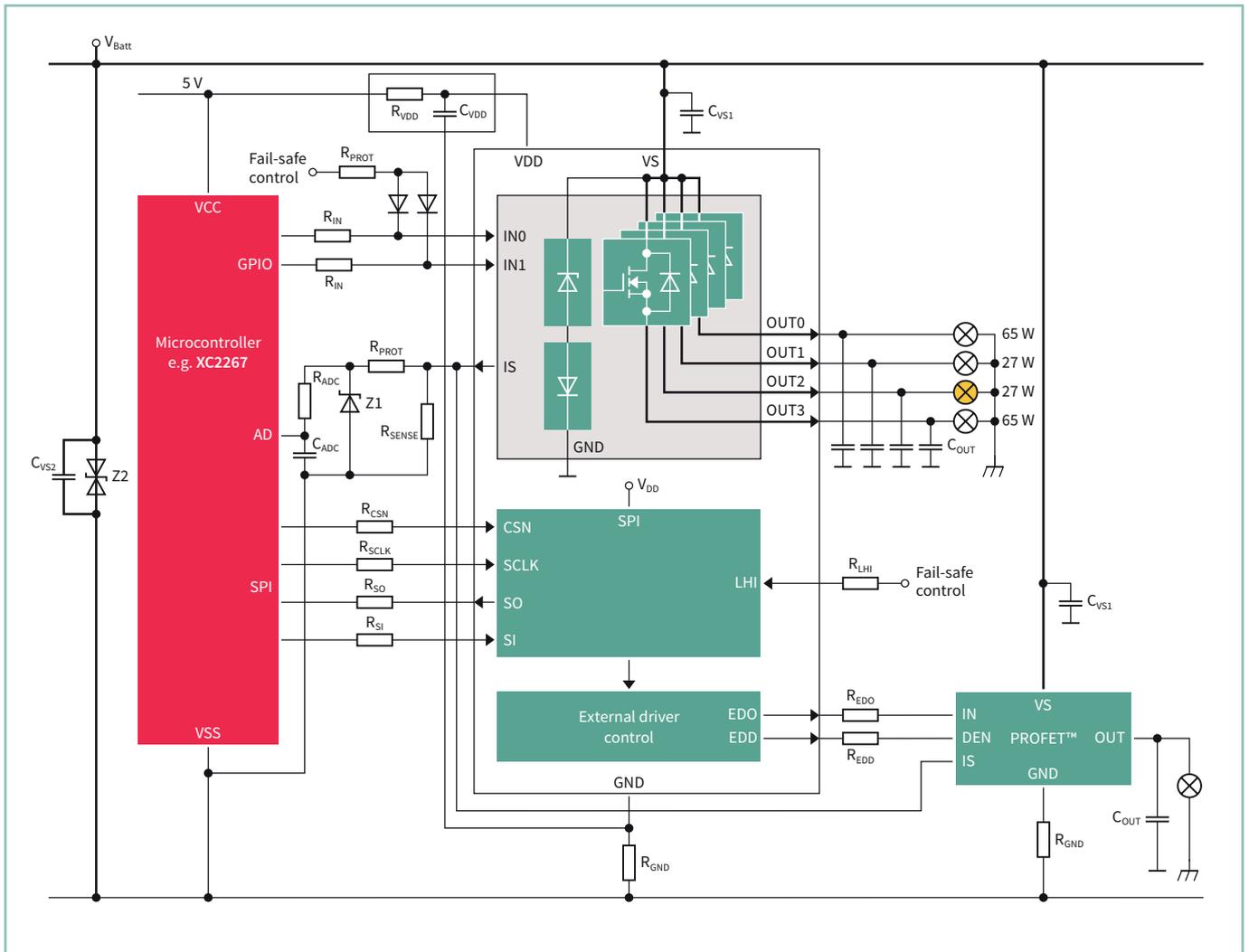


Figure 5: SPOC™ +2 multi-channel high-side switches provide both control and diagnostic capability via SPI.

The last family, the single output **Power PROFET™** devices³ 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 behavior replicates a fuse in short circuit scenarios, while also providing thermal protection. 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 6). The upcoming ISO26262-ready new generation of Power PROFET™ will be the most comprehensive power drivers ever in terms of technology, current capability, size & price.

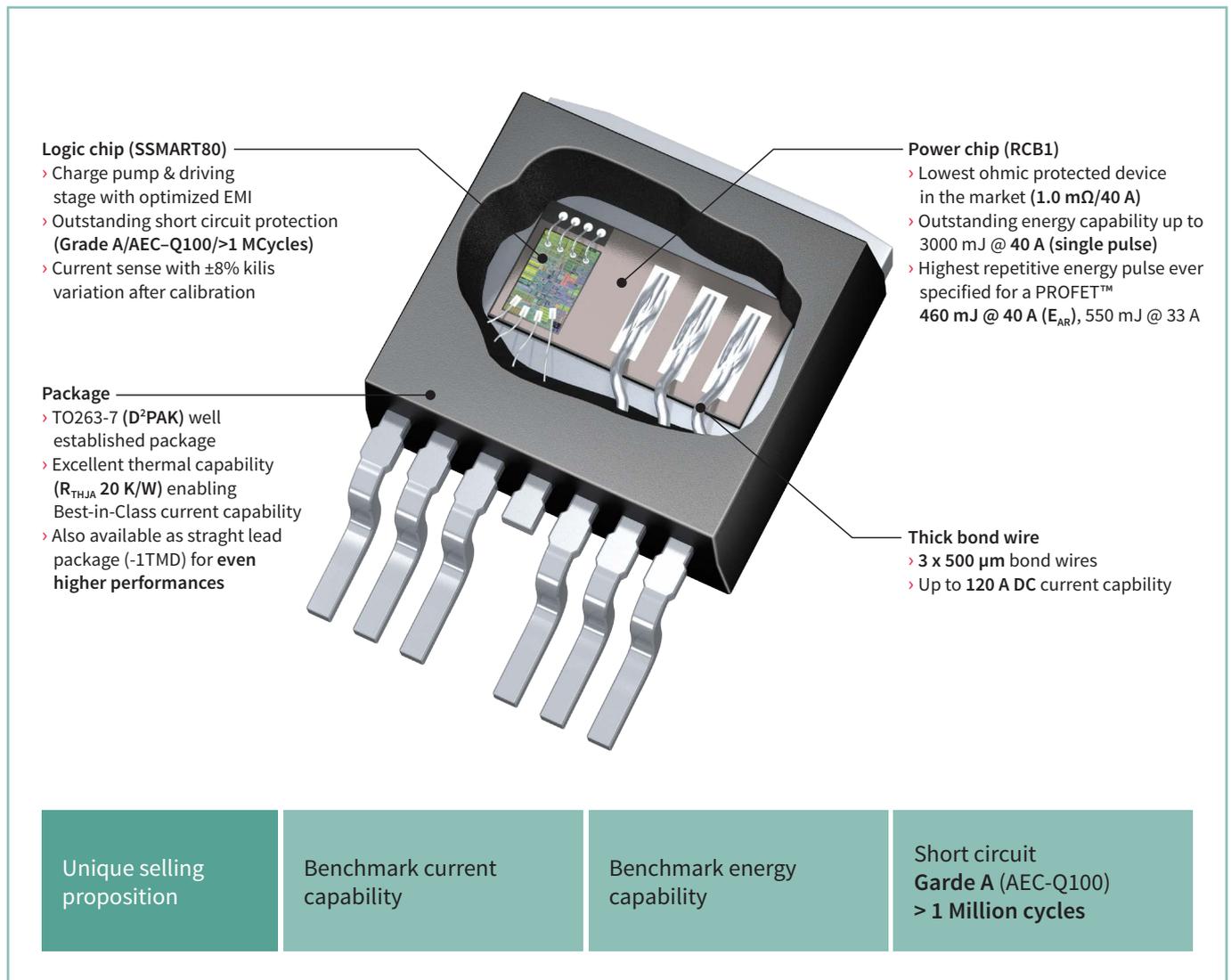


Figure 6: The Power PROFET™ series complements today's start-stop CO2 saving features with their outstanding energy capability and PWM support.

4. 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 7 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 AD 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 12 V battery or via a DC-DC converter providing 12 V from the 48 V battery or from the high-voltage battery. A combination of [power MOSFETs](#) and [AUIR3241S](#) gate drivers are used to implement a logical 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, PROFET™s provide a direct connection to the 12 V 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.

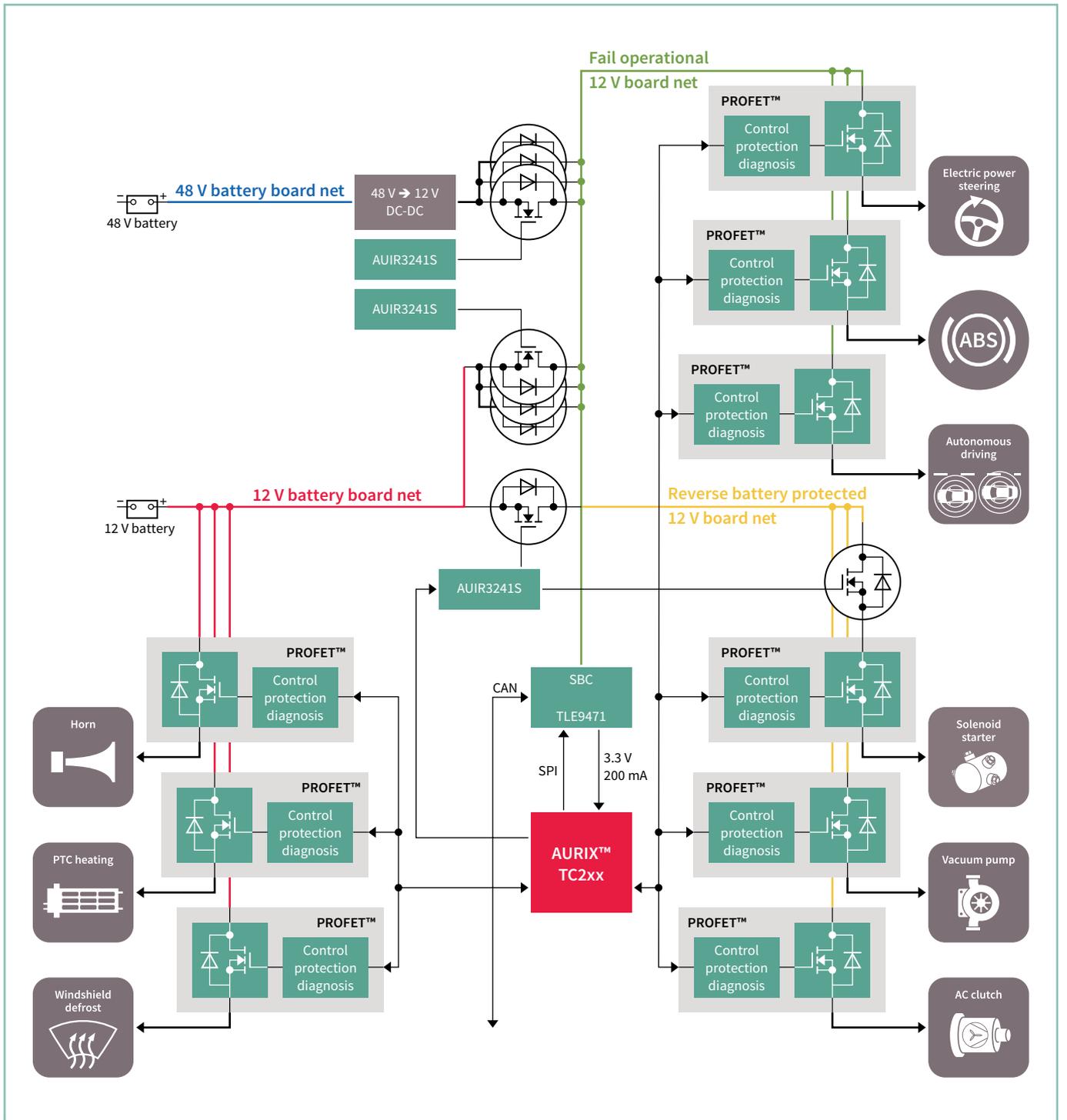
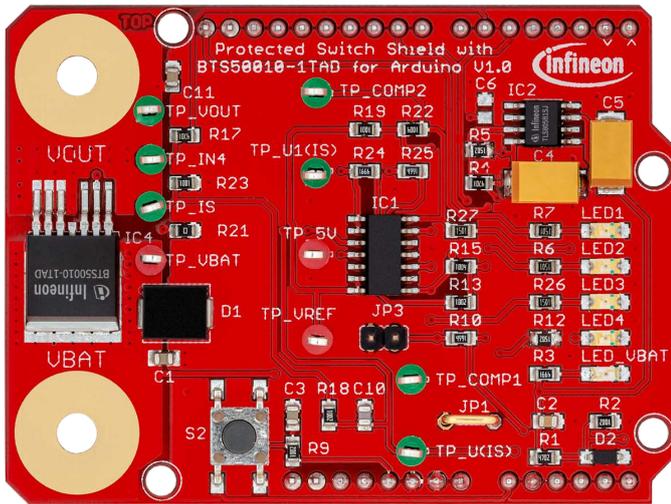


Figure 7: Power distribution in the vehicle will be split into different power domains, along with back-up power support for safety critical systems



Evaluation of these high-side switching solutions is simplified with a range of development boards on offer. The [SHIELD BTS50010-1TAD](#)⁶ is one such option designed to function with the Arduino form factor development boards, enabling a fast and simple appraisal (figure 8).

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

5. Summary

With a lot of vehicle electronics having moved to silicon-based future technology, 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.

6. Notes and temporary references

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3. <https://www.infineon.com/cms/en/product/power/smart-low-side-high-side-switches/automotive-smart-high-side-switch-profet/power-profet/>
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