Relay replacement within automotive power distribution

Smart switch versus relay: detailed comparison

About this document

Scope and purpose

This document explains semiconductor-based power distribution in automotive applications. First, it lists the key characteristics of smart switches and then gives a detailed comparison between smart switches and electromechanical relays.

Intended audience

Readers familiar with electromechanical relays and fuse-based power distribution systems, who seek a better understanding of smart power distribution systems based on semiconductor smart switches.

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1 Smart switch versus relay: detailed comparison

1.1 Dimensions, volume, and weight

Smart switches clearly outperform relays with regard to volume and weight. As it can be seen in the figure below, even the smallest PCB relays are still significantly bigger than smart switches based on D^{2}PAK, DPAK or TDSO-8 packages. Relays are also much heavier. A PCB relay weighs approximately 10g, whereas a smart switch is in the range of 1g or less for small packages.

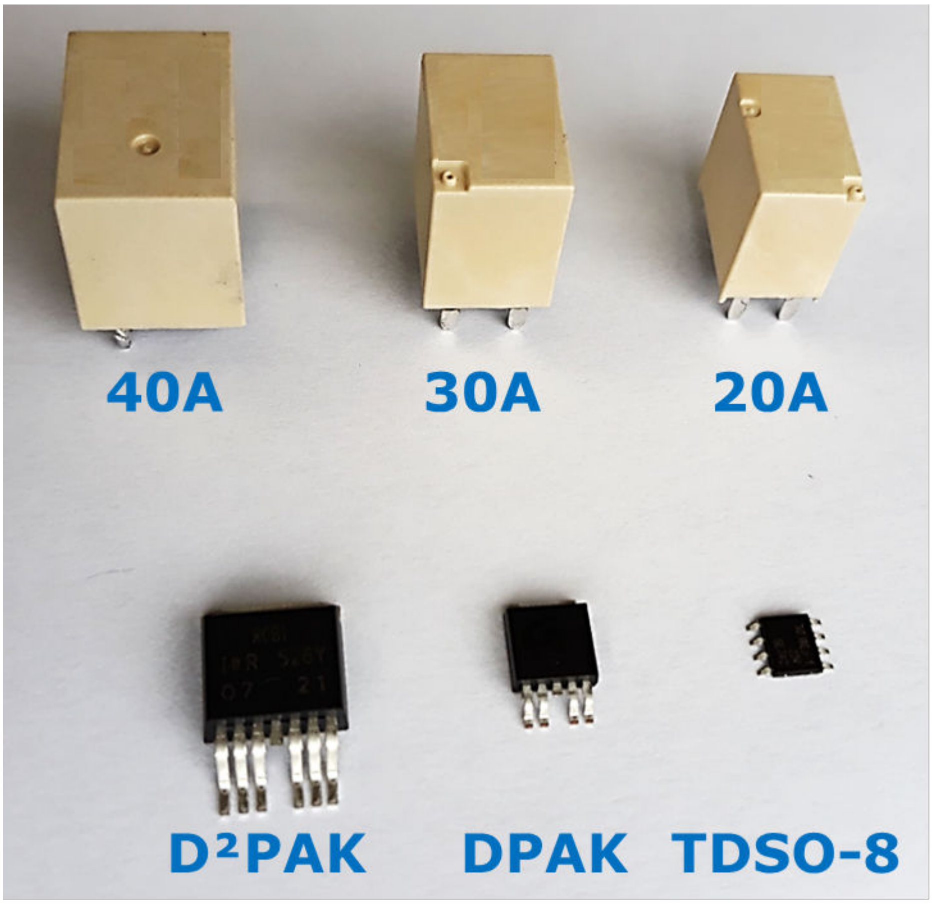


Figure 1 Comparison of the size and volume of relays and smart switches

1.2 Power dissipation

1.2.1 Relay

There are two two factors that contribute to the total power dissipated inside a relay:

- Power dissipated in the control coil. A typical 12 V plug-in relay has a coil resistance of 103 Ω in parallel with a protection resistor of 680 Ω. The equivalent resistance is 90 Ω. Assuming a typical battery voltage of 13.5 V, the power dissipated in the coil is: $P_{\mathrm{Coil}} = V_{\mathrm{BAT}}^2/R = 13.5^2/90 = 2.03$ W
- Power dissipated in the contact itself. A typical value for the contact resistance of a 30 A relay is 3 mΩ. The power dissipated inside the contact will vary according to $P_{\mathrm{Contact}} = R_{\mathrm{Contact}} \times I_{\mathrm{Load}}^2$

Figure 2 shows the power dissipated in the relay contact according to the load current, from 0 to 30 A.

The total power dissipated inside the relay is therefore: $P_{\mathrm{Relay}} = P_{\mathrm{Coil}} + P_{\mathrm{Contact}}$

1.2.2 Smart switch

The power dissipated inside the smart switch also has two contributing factors:

- Operating power, which is the power dissipated in the control circuit driving the MOSFET. The operating current is often in the range of 2 milliamps, so $P_{\mathrm{Operating}} = 0.002 \times 13.5 = 0.027$ W
- Power dissipated in the MOSFET. A 30 A relay can usually be replaced by a smart switch with an $R_{\mathrm{DS(ON)}}$ of 2.5 mΩ. The corresponding power dissipation is: $P_{\mathrm{RDS(ON)}} = R_{\mathrm{Contact}} \times I_{\mathrm{Load}}^2$, which is also shown in Figure 2

The total power dissipated inside the relay is therefore: $P_{\mathrm{SmartSwitch}} = P_{\mathrm{Operating}} + P_{\mathrm{RDS(ON)}}$

1.2.3 Graphic comparison

Figure 2 plots the total power dissipation for the relay and for the smart switch. The figure shows that the savings with the smart switch are at least 2 W. The benefit of the smart switch is also that the power dissipation is essentially linked to the load current. If the load has various operating modes, including an idle mode or a sleep mode, then the smart switch power dissipation scales with the current and results in very low values, unlike the relay, which dissipates at least 2 W.

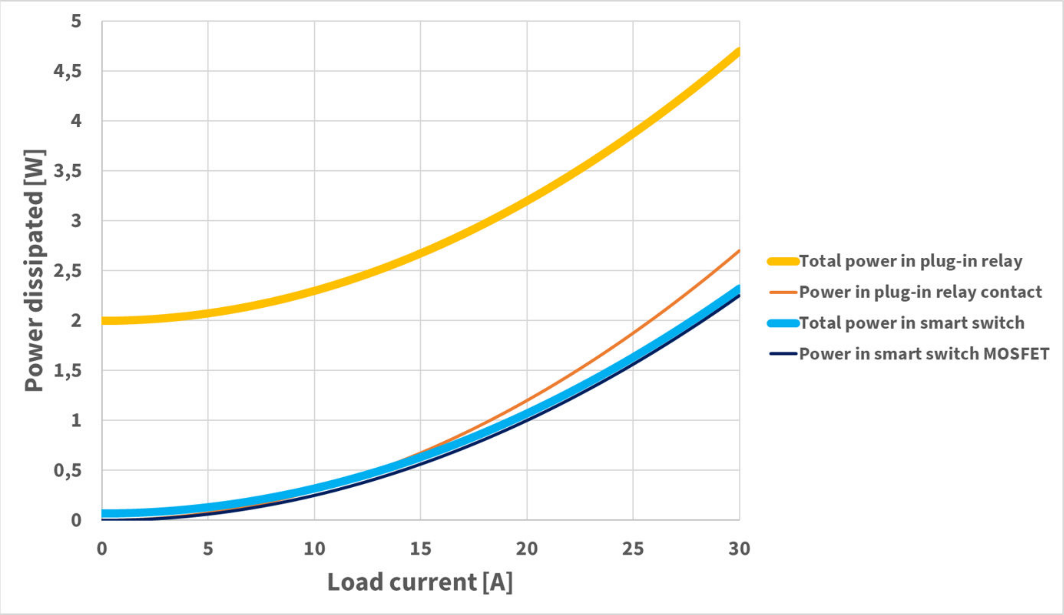


Figure 2 Comparison of the power dissipation in a relay versus a smart switch

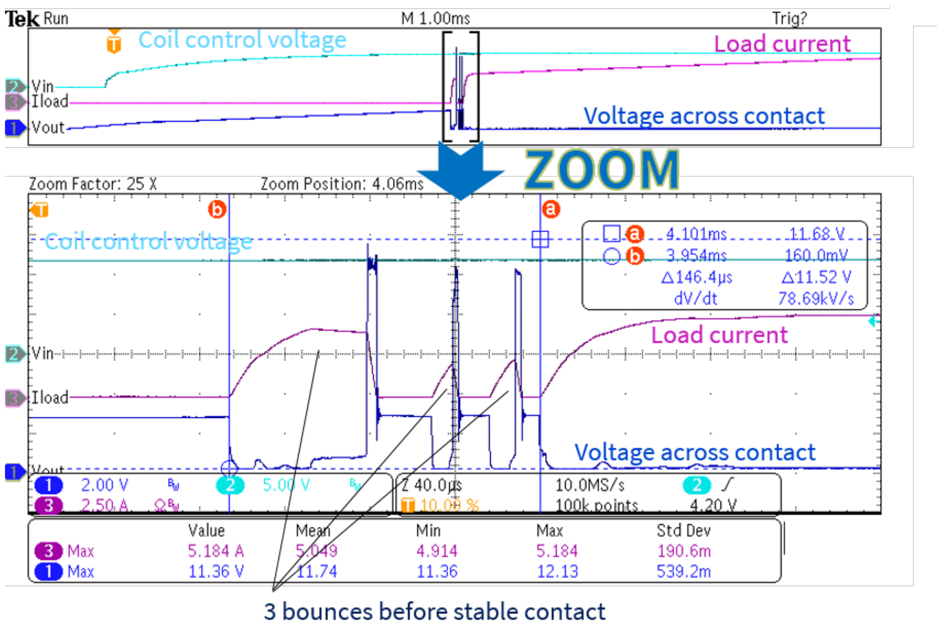
1.3 Switching behavior

1.3.1 Bounces with relays versus smooth slopes with smart switches

When capturing the load current waveform of the output of a relay used in a high-side switch configuration, it is visible that the contact is bouncing. The current exhibits several peaks before it is stable. This generates quite severe electromagnetic interferences (EMI), which can disturb electronic boards in the near vicinity.

The higher the voltage applied on the control coil of the relay, the higher the magnetic field and the faster the contact moves. It can be observed that the amount of bouncing also increases together with the coil voltage, from no bounces close to the minimum operating voltage (6 V typically) up to 5 bounces when 13.5 V is applied to the coil.

Figure 3 illustrates the bouncing behavior when 12 V is applied to the coil. Here, 3 bounces are visible.



	Value	Mean	Min	Max	Std Dev
3 Max	5.184 A	5.049	4.914	5.184	190.6m
1 Max	11.36 V	11.74	11.36	12.13	539.2m

Figure 3 Contact bouncing visible on current and voltage waveforms (switch ON)

The switch OFF behavior does not exhibit bounces. However, it is not truly optimized in terms of EMI since the slopes are not under control. An example of the switch OFF behavior is shown in Figure 4.

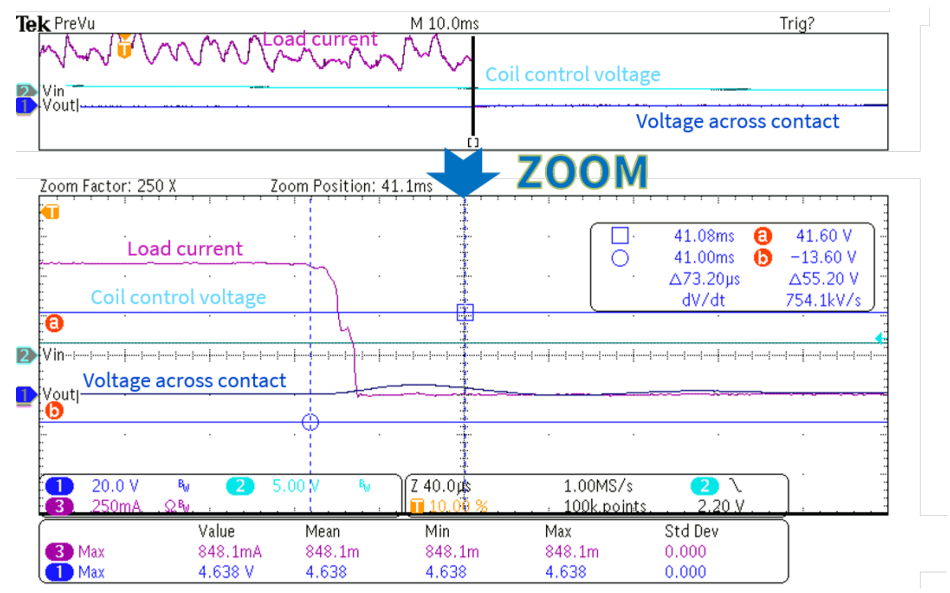


Figure 4 Load current waveform at contact opening (load is a vacuum pump)

In comparison, the switching waveforms with a smart switch are clean and smooth. The gate driver is designed to control the rise and fall slopes such that they generate minimal EMI. This is illustrated in Figure 5.

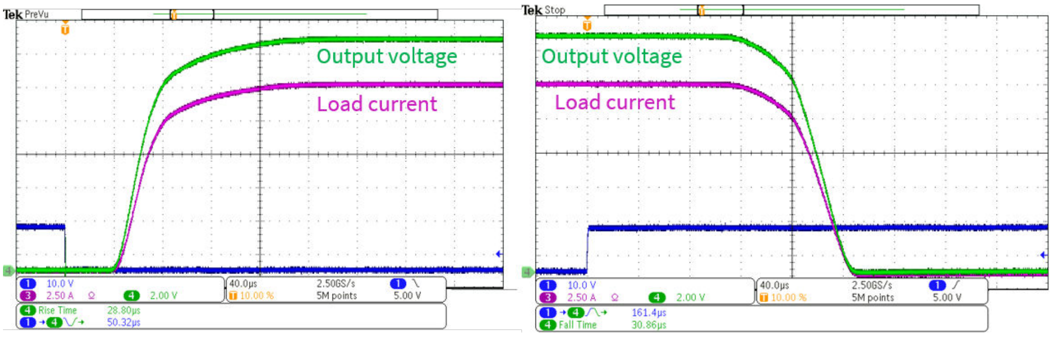


Figure 5 Example of the switching waveforms with a 12 V automotive smart switch

1.3.2 Dry switching

The contact inside a relay is sensitive to the current at opening and closure.

To ensure a long lifetime of the relay, manufacturers strongly recommend avoiding “dry switching”, where there is no load current at operate and release. Indeed, a minimum current is required at release (the contact opening), so that a reasonable arcing takes place and cleans up the contact surfaces.

On the other hand, when the current is too high at release, the arcing can damage the contact surface. This would typically happen when driving a highly inductive load. For more information, refer to Robustness when exposed to inductive demagnetization. These minimum and maximum currents at operate and release are provided in the relay datasheets.

Dry switching is not a concern for smart switches. The capability of smart switches here is in the range of 10^{15} cycles. Consequently, datasheets for smart switches do not specify a minimum load current at switch ON or OFF.

1.3.3 Robustness when exposed to inrush currents

Several types of loads generate an inrush current at power ON:

- Brushed DC motors
- Incandescent bulbs
- Electronic control units (ECUs) with filtering capacitance on their supply terminal. The ECUs could be driving DC motors or ADAS features, such as cameras and radar

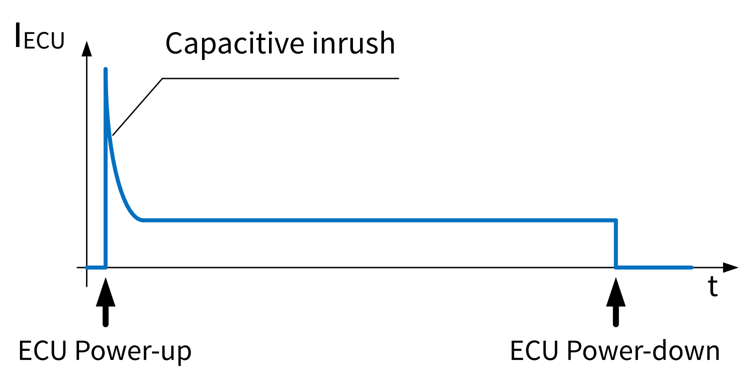


Figure 6 **Current profile of an ECU load with inrush at power ON**

The contact inside a relay is sensitive to the inrush current. Indeed, the bouncing generates a sequence of closing and opening of the contact. When opening the contact, arcing can happen. The higher the current, the stronger the arc and the more severe the contact damage. Due to this sensitivity, relay datasheets specify the maximum current at operate (switch ON for a normally open (NO), relay).

The smart switch does not have any arcing but the inrush current is a stress that generates a transient temperature increase due to the temporary high current. In addition, the smart switch protection may interpret the inrush as a short-circuit and trigger an overcurrent protection mechanism. For more information, refer to Overcurrent protection.

To select the smart switch correctly, the current profile during the inrush of the load must be characterized. Using this information, the compatibility with the smart switch can be assessed, based on two considerations:

- Peak current capability. For more information, refer to Overcurrent protection
- Dynamic thermal response. For more information, refer to Overtemperature protection

1.3.4 Robustness when exposed to inductive demagnetization

Several types of load exhibit an inductive behavior:

- Control coil of a relay
- Valves
- Solenoids
- DC Motors

The inductor in the load has two main characteristics: its inductance (L) and its series resistance (R_L).

Considering the inductance only (L), the relationship between the slope of the current (dI_L/dt) and the voltage applied across the inductance (V_L) is based on the well-known formula:

$$\frac{dI_L}{dt} = \frac{1}{L} \times V_L$$

It is visible that to change the direction of the current in an inductance, it is necessary to invert the voltage polarity applied on the inductor, as shown in Figure 7.

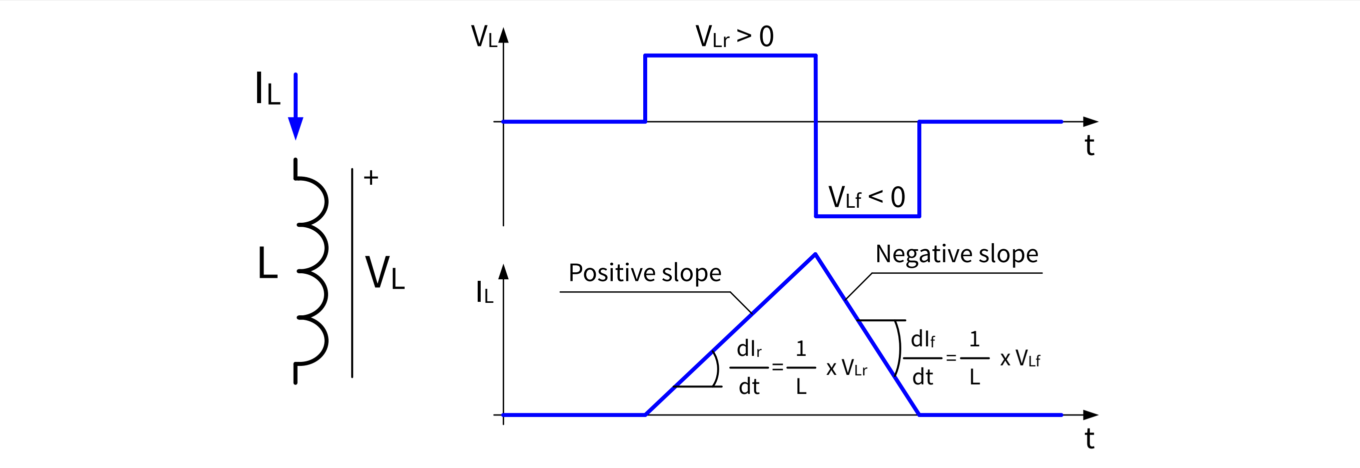


Figure 7 **Current slopes in an inductance based on the voltage applied across it**

The consequence is that it is necessary to apply a negative voltage across the inductance to remove the current flowing through it.

A relay does not actively control this negative voltage. It can therefore be exposed to quite high voltages in absolute value (several hundred volts). At the contact level, there is usually an arc taking place. If the inductance value and the current value are high, then the arc will be severe and can damage the contact surface and jeopardize the relay's lifetime. In such cases, vendors recommend using external clamping components, such as freewheeling diodes and transient voltage suppressors (TVS), to protect the relay contact.

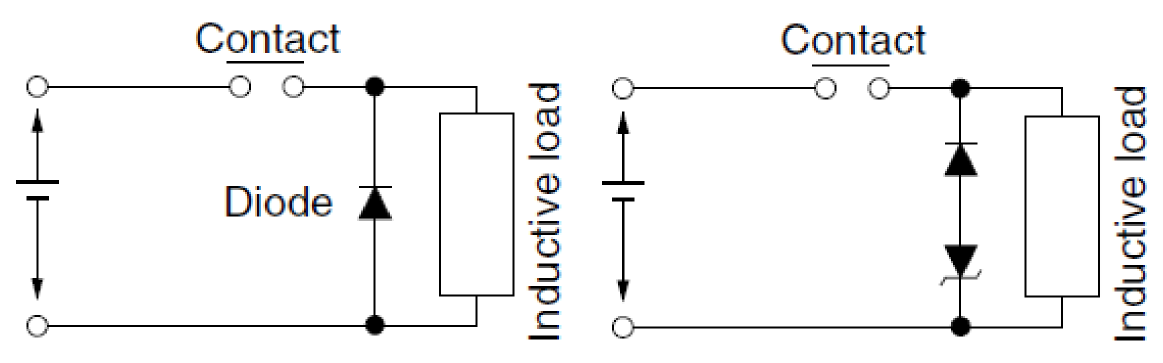


Figure 8 **Example of protection circuitries for relays driving inductive loads**

Smart switches come with a feature called smart clamping, which generates a controlled negative voltage across the inductor when the internal MOSFET switches OFF. The value of this voltage is $V_L = V_{BAT} - V_{DS(CL)}$ where $V_{DS(CL)}$ the clamping voltage across the power MOSFET is within the smart switch. The smart switch behaves very similarly to a Zener diode. Since $V_{DS(CL)}$ is more than twice larger than V_{BAT}, V_L is negative:

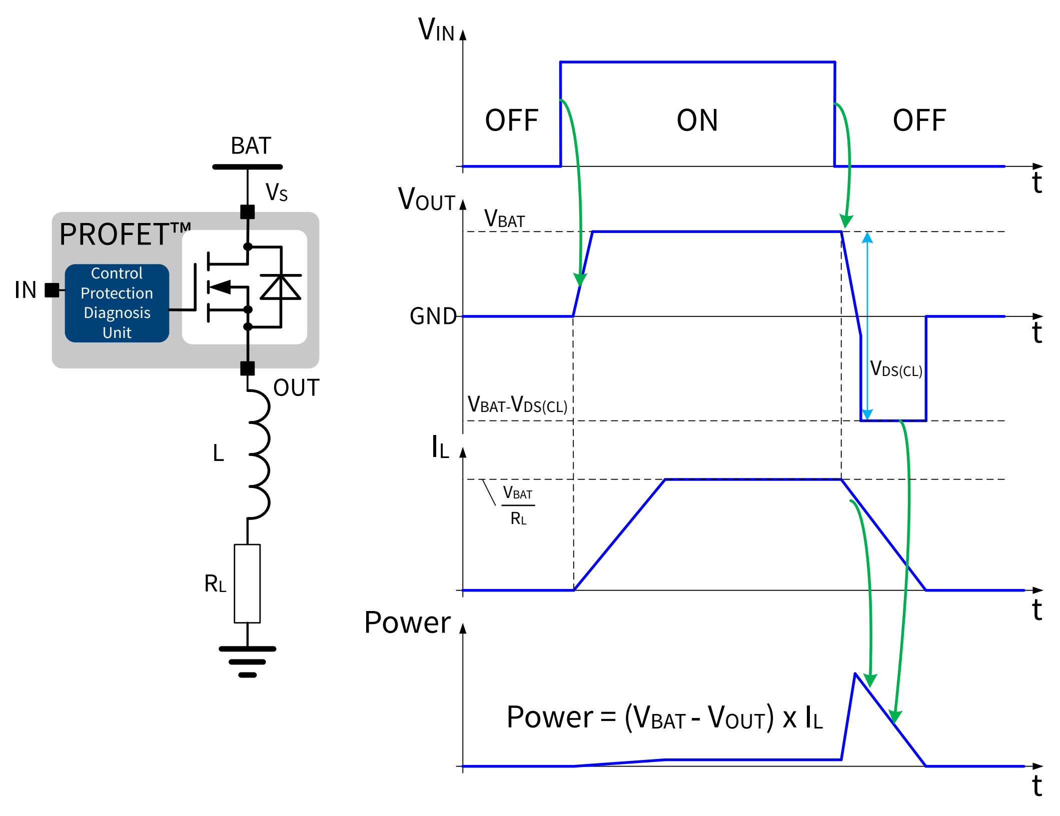


Figure 9 Voltage and current waveforms during an inductor demagnetization

As can be seen on the last waveform (Power), the output power transistor in the smart switch is exposed to a very high power pulse during the inductor demagnetization. Indeed, for high current PROFET™, the clamping voltage is in the range of 40 V while the current can be several tens of amperes. The resulting peak power can reach several kilowatts.

It is therefore critical to assess if the application conditions (current in the load, inductance and resistance of the load) lead to thermal stress, which can damage the smart switch. So similar to relays, it may be necessary to use external clamping components (freewheeling diodes and transient voltage suppressors (TVS)) to protect the smart switch from strong demagnetization.

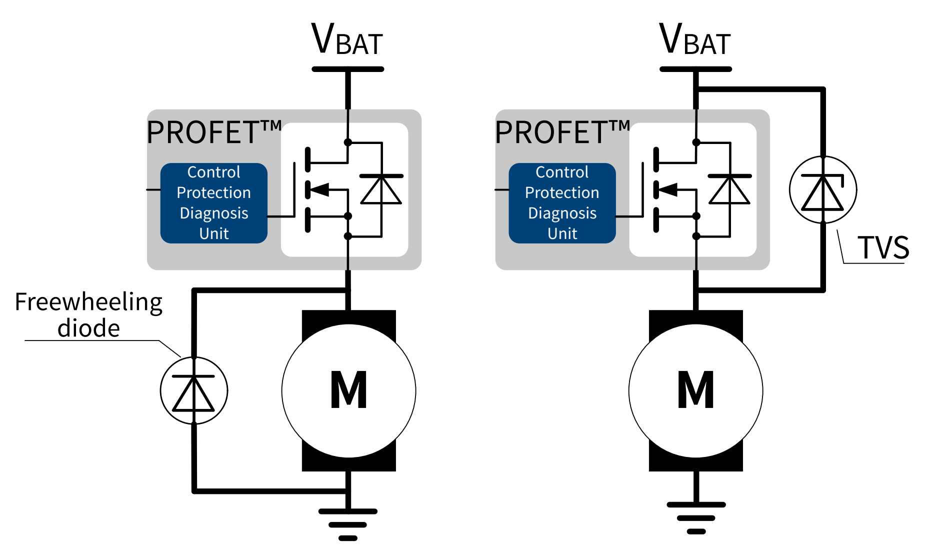


Figure 10 Example of protection circuitries for smart switches driving inductive loads

1.3.5 Switching cycles

Datasheets for relays usually refer to electrical endurance and mechanical endurance, as there is a limited number of operate/release cycles allowed. In general, mechanical endurance is better than electrical endurance. Mechanical endurance is in the range of a million cycles. Electrical endurance is in the range of a hundred thousand.

Electrical endurance is not straightforward to assess for relays. Electrical endurance is highly dependent on the load characteristics. Relay manufacturers usually specify a number of activations for a specific load with a specific activation profile, depending on whether at the time the load is ON and OFF. One way to improve the electrical endurance is to oversize the relay. A 30 A relay used for a 10 A load exhibits a better electrical endurance than a 20 A relay. But it comes with a higher cost also.

For loads that require a high number of activations, estimated at half a million, over the lifetime of a car, smart switches are clearly the best choice since they can survive more than 10^{15} activations. Dry switching it not an issue at all, as seen in Dry switching. The only limitation that may apply happens with inductive loads without a freewheeling diode. In such a case, the demagnetization energy is burned inside the MOSFET, which generates a transient temperature increase. Datasheets for smart switches usually contain an E_{AR} parameter, which indicates the maximum energy for which the smart switch can survive at least 1 million activation cycles without any significant shift in its electrical characteristics. If it is required to achieve a higher number of activation cycles, the solution is to use an external freewheeling diode as described in Robustness when exposed to inductive demagnetization.

1.4 Protection mechanisms

There are three main conditions under which the MOSFET inside the smart switch may be jeopardized in the application:

- Overcurrent (which occurs mainly if there are load short circuits)
- Overtemperature
- Reverse battery

1.4.1 Overcurrent protection

Relays and smart switches are mostly in danger when the load is short-circuited.

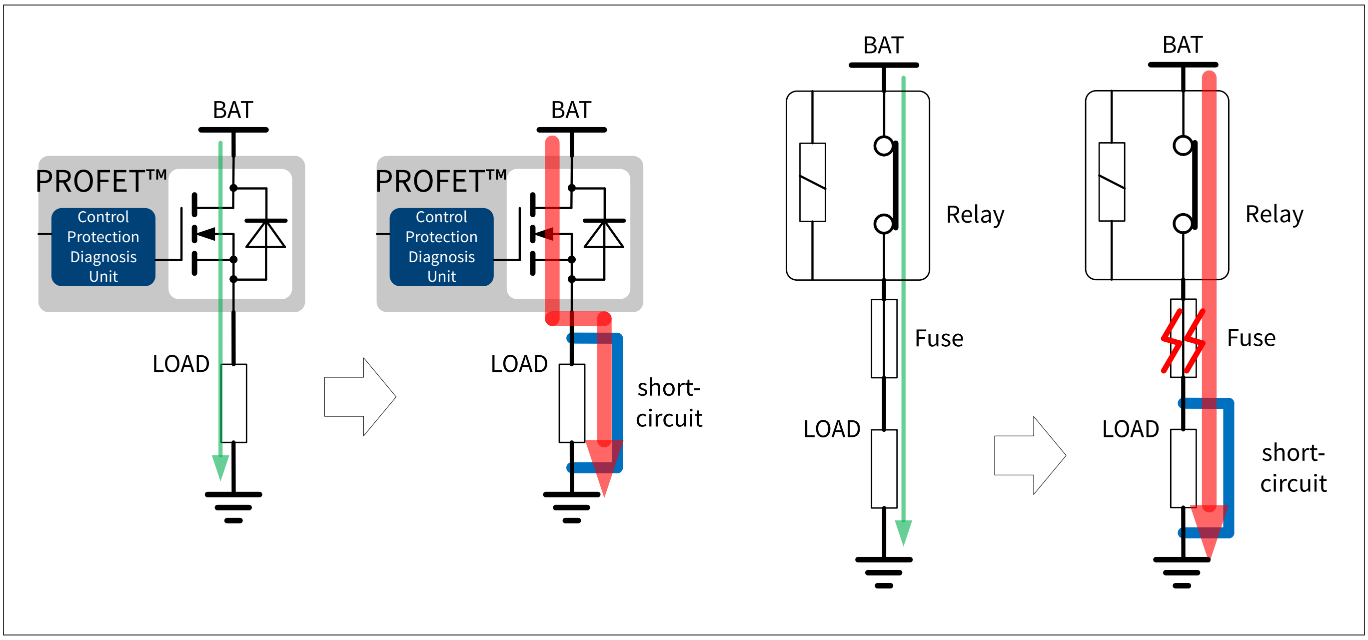


Figure 11 **Overcurrent when there is a load short-circuit**

The relay has no internal protection against overcurrent. It must rely on an external protection, which is usually fuse-based. When exposed to a high current, the fuse melts and opens so that current can no longer flow. Once the short-circuit is removed, the fuse must be replaced to be able to supply the load once again.

Unlike the relay, the smart switch has an integrated protection mechanism, which compares the current flowing through the MOSFET with a reference threshold. When the current is above this reference threshold, the MOSFET is usually switched OFF.

Some smart switches do not immediately switch OFF. Instead, they move to a current limitation mode, where the MOSFET delivers a limited current to the load. For such smart switches, the final protection is the overtemperature protection because the MOSFET temperature keeps increasing in the current limitation mode.

The main difference with a fuse is that the smart switch can be switched on again once the short-circuit is removed because there are no parts to replace.

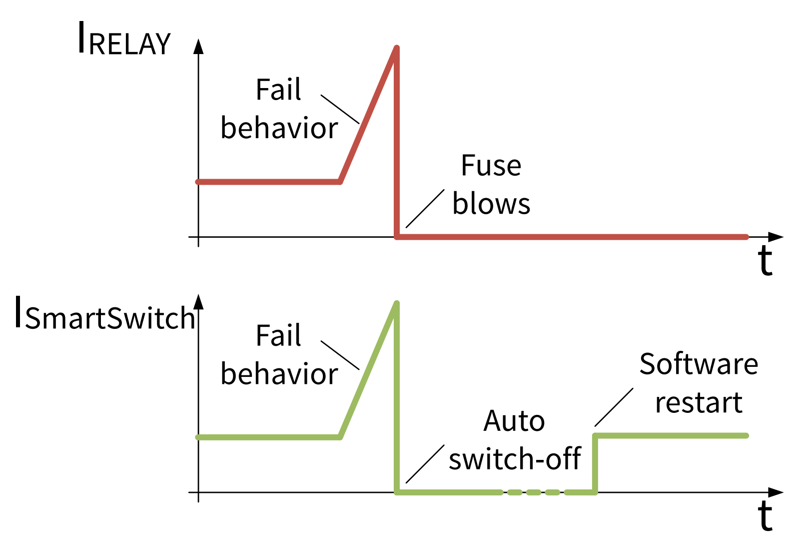


Figure 12 Comparison of protection schemes: relay and fuse versus smart switch

1.4.2 Overtemperature protection

Both the relay and the smart switch have a specified temperature limitation. Their internal temperature has to be limited, otherwise their structure becomes damaged.

For the relay, there are 3 contributing factors to the internal temperature:

- The power dissipated in the control coil (V_{Coil}^2/R_{Coil})
- The power dissipated in the contact due to its resistance ($R_{Contact}$ x I_{Load}^2)
- The ambient temperature outside the case of the relay

Some relay manufacturers indicate in their datasheets:

- The internal temperature increases according to various coil voltages, which impacts the power dissipated in the control coil
- The internal temperature increases according to various currents flowing through the contact, which impacts the power dissipated in the contact

Refer to Figure 13.

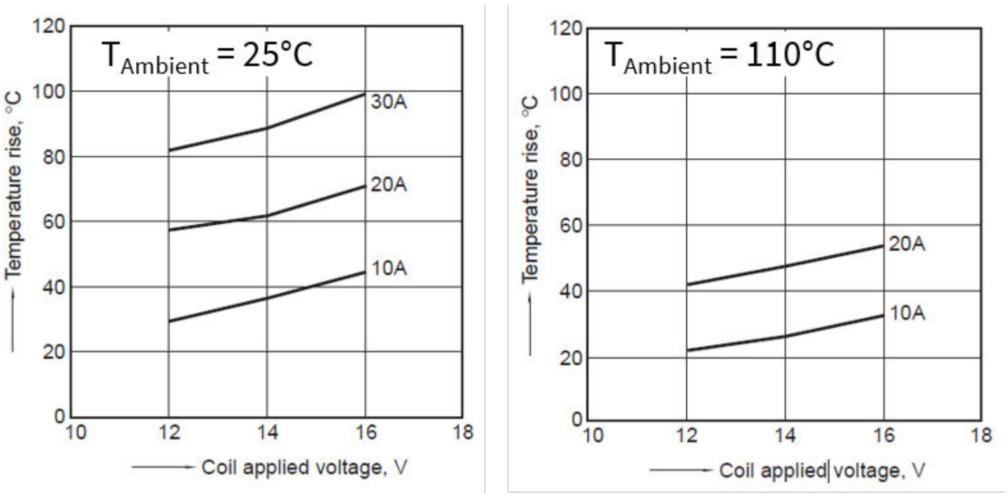


Figure 13 Temperature rise inside a relay, I_{LOAD} = 30 A not possible at $T_{Ambient}$ = 110°C (right)

Here again, there is no protection inside the relay. The application (ambient temperature, applied coil voltage, and load current) has to be checked to ensure that the capabilities of the relay are not exceeded.

For the smart switch, 3 factors contribute to the internal temperature:

- The power dissipated in the control circuit (V_{Bat} x $I_{Operating}$)
- The power dissipated in the power MOSFET due to its resistance ($R_{DS(ON)}$ x I_{Load}^2) when the MOSFET is switched ON or during demagnetization at switch OFF, as shown in Chapter 1.3.4
- The ambient temperature outside the package of the smart switch

Generally, the first contributing factor can be ignored. The power dissipated by the control circuit driving the power MOSFET is, in general, below 50 mW , so its impact is negligible.

The main contributor is the power dissipated in the power MOSFET. Under some conditions, the MOSFET is exposed to a high ambient temperature together with a high current which, even if below the overcurrent threshold, is above the DC current capability of the MOSFET. These conditions generate a significant increase of the MOSFET's temperature and can damage it.

The internal protection control circuitry continuously senses the MOSFET temperature and switches it OFF if its absolute temperature becomes too high. In such a case, the power dissipated inside the MOSFET (and also the MOSFET temperature) immediately reduces, protecting the device from destructive failure and the system from overload.

1.4.3 Reverse battery protection

Car manufacturers usually stipulate that a reverse battery polarity connection must not be able to damage anything in the vehicle.

Some loads are not affected by reverse polarity. A typical example of such loads is a windshield defroster: Such a heating resistance generates some heat whatever voltage polarity is applied.

For other loads, reverse polarity can create severe damage. For instance, some pumps are designed to operate in one mechanical direction only and break if exposed to a reverse polarity because it forces the pump to run backwards.

When a relay is used to switch on the power supply of a load, the reverse battery protection is quite straightforward. In the case of a normally open (NO) relay driving motor, the coil driver usually has a body diode because the coil driver is most commonly based on a MOSFET. For more information, refer to 2.. Scenario (1) on Figure 14 illustrates such a configuration based on a low-side smart switch, which is part of the Infineon HITFET™ family.

When the battery polarity is reversed, due to this body diode, the control coil is activated and the relay contact is closed. The load is therefore supplied with reverse polarity (scenario (2) in Figure 14).

If there is a risk of damage in such a configuration, you can mitigate the risk using a low-cost small signal diode, such as 1N4148, that can be used to block the current in the low-side smart switch body diode The relay contact is then opened upon polarity reversal and no current flows into the load, so it is safe. This is illustrated in scenario (3) in Figure 14.

In summary, with a relay, only the coil control path may have to be blocked with a diode, depending on whether the load can tolerate being reverse biased. This is fortunately a low-current path, which means you can use a low-cost small signal diode.

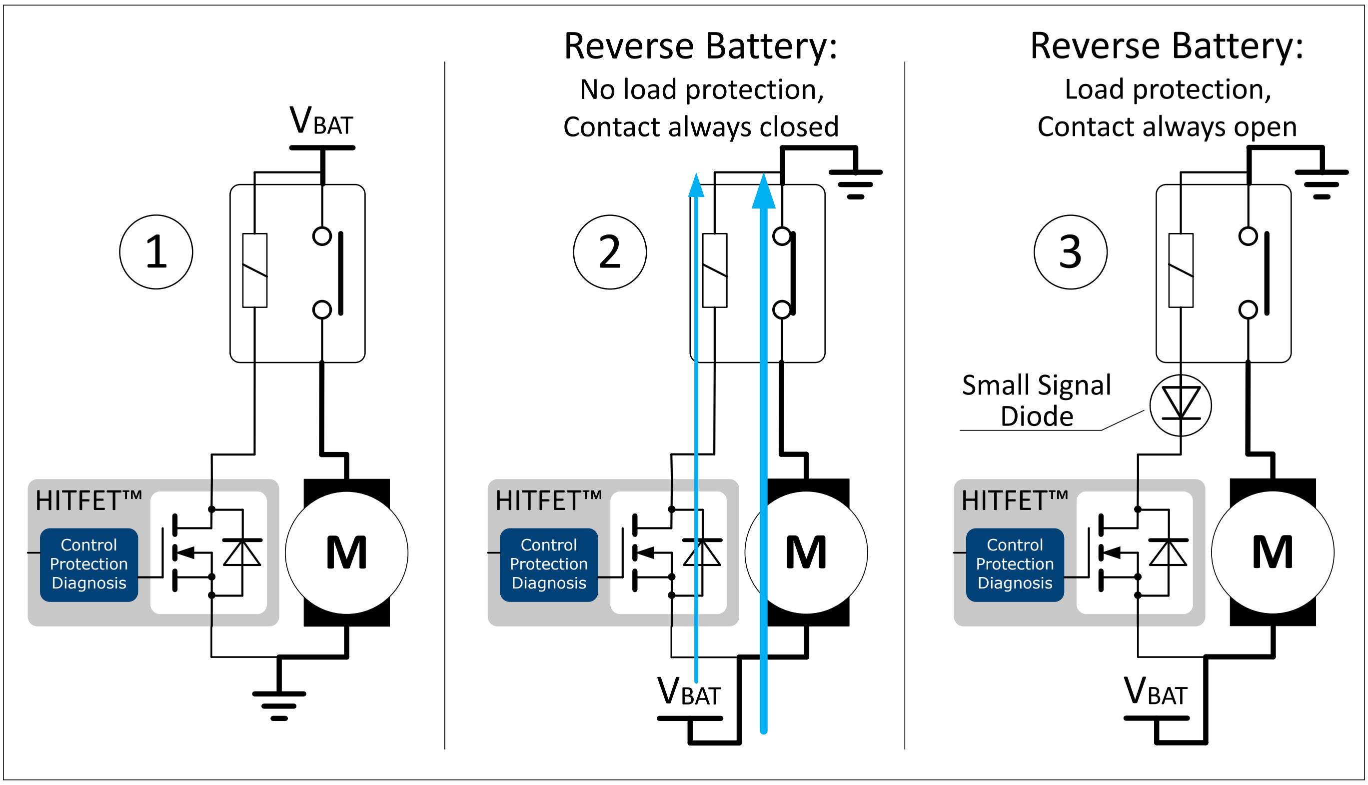


Figure 14 **Reverse battery handling with a relay**

For the smart switch, reverse polarity is not only a potential issue for the load, it can also be an issue for the power MOSFET itself. The MOSFET body diode allows the current to flow through the load when battery polarity is reversed. A rough calculation (considering a 5 mΩ $R_{DS(ON)}$ on a smart switch) shows that the power losses are much higher when the current flows through the diode than when it flows through the MOSFET itself:

- Power losses in the diode: $P_{Diode} \approx 1\ V \times I_{Motor}$. If $I_{Motor} = 20\ A$ --> $P_{Diode} \approx 20\ W$
- Power losses in the NMOS: $P_{NMOS} = R_{DS(ON)} \times I_{Motor}^2$. If $I_{Motor} = 20\ A$ and $R_{DS(ON)} = 5\ m\Omega$ --> $P_{NMOS} = 2\ W$

One protection method for the MOSFET consists of switching it ON, when the control circuitry detects a reverse battery connection. In this way, the power losses are reduced to a value similar to normal forward operation of the load, keeping the smart switch from reaching a potentially damaging temperature. Refer to scenario (2) in Figure 15. For Infineon devices, this feature is called ReverSave™.

This protection applies to the MOSFET only, not to the load itself. Indeed, the load is still exposed to the battery voltage and current in reverse polarity, which is an issue if the load is damaged in such conditions. If the load requires a protection, it is necessary to add a diode function as a blocker to the supply line of the smart switch. Here again, for power dissipation reasons, it is usually necessary to use a power MOSFET with inverted source and drain connection, which results in lower power than a traditional diode, as illustrated in Figure 15, scenario (3):

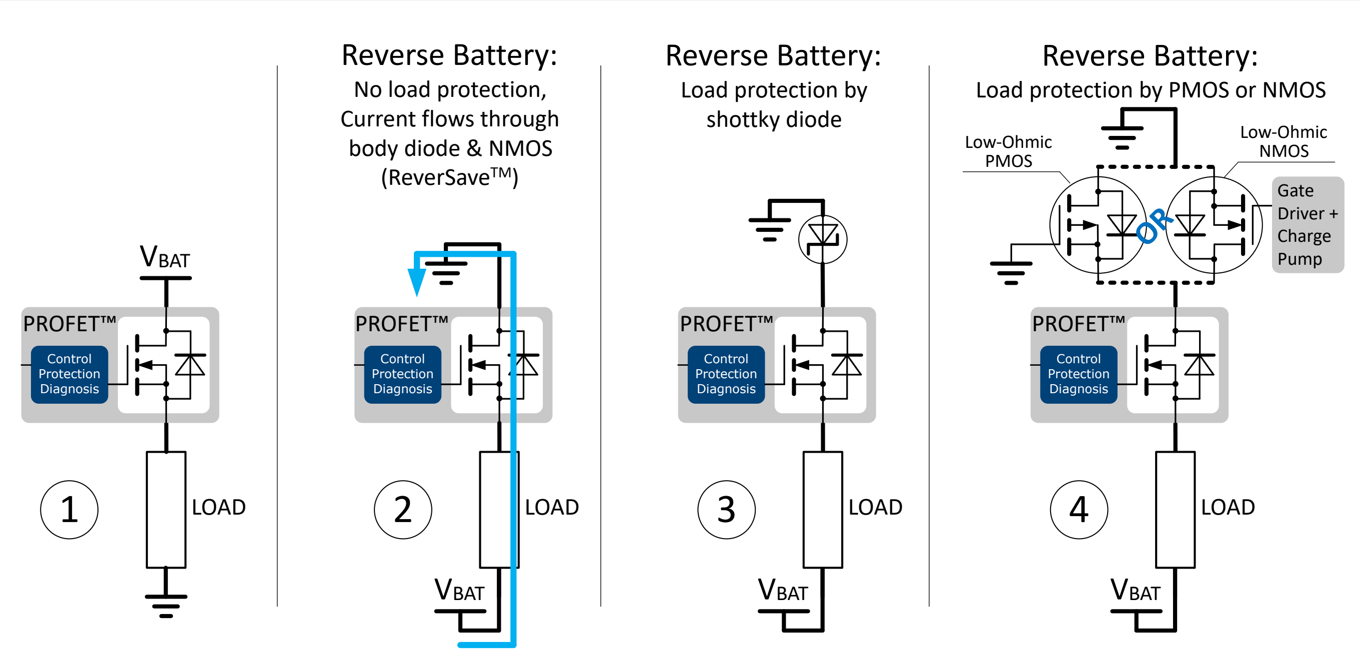


Figure 15 **Reverse battery handling with a smart switch**

Scenario (3) in Figure 15 illustrates a solution based on a Schottky diode, used to block the reverse current in battery reversal. The solution can be used for currents below a few amperes, with the drawback that there is a voltage drop across the diode (typically 0.5 V) and the diode dissipates a significant power for high currents (P > 2.5 W for I_{LOAD} > 5 A).

Scenario (4) in Figure 15 shows that there are two other options to implement protection for high current loads:

- A PMOS with the gate connected to the ground potential, such that it is always ON when the battery has the correct polarity and it is OFF if the battery polarity is incorrect
- An NMOS together with a gate driver plus a charge pump. The charge pump is necessary to generate a gate voltage higher than the battery voltage when the battery polarity is correct. Infineon offers a family of components, called System Basis Chips (SBC) Lite, which embeds a charge pump. The charge pump can be used to drive such a reverse block NMOS

Additional scenarios must be considered if the load is highly inductive and the smart switch must be protected by additional external components against inductive demagnetization. A blocking component is especially necessary when a freewheeling diode is used, because the freewheeling diode and the smart switch form a circuit with two series diodes. This circuit allows virtually unlimited current to flow when exposed to reverse polarity (scenario (2) on Figure 16). For the reverse blocking protection, two options are possible:

- The load can be exposed to reverse battery. In such a case, a medium-cost MOSFET can be inserted in the ground path of the freewheeling diode as a blocker. The NMOS is always ON when the battery has the correct polarity and it is OFF if the battery polarity is incorrect. Refer to scenario (3) in Figure 16
- The load cannot be exposed to the reverse battery. The protection scheme is the same as the one used in scenario (3) in Figure 15. Refer to scenario (4) in Figure 16

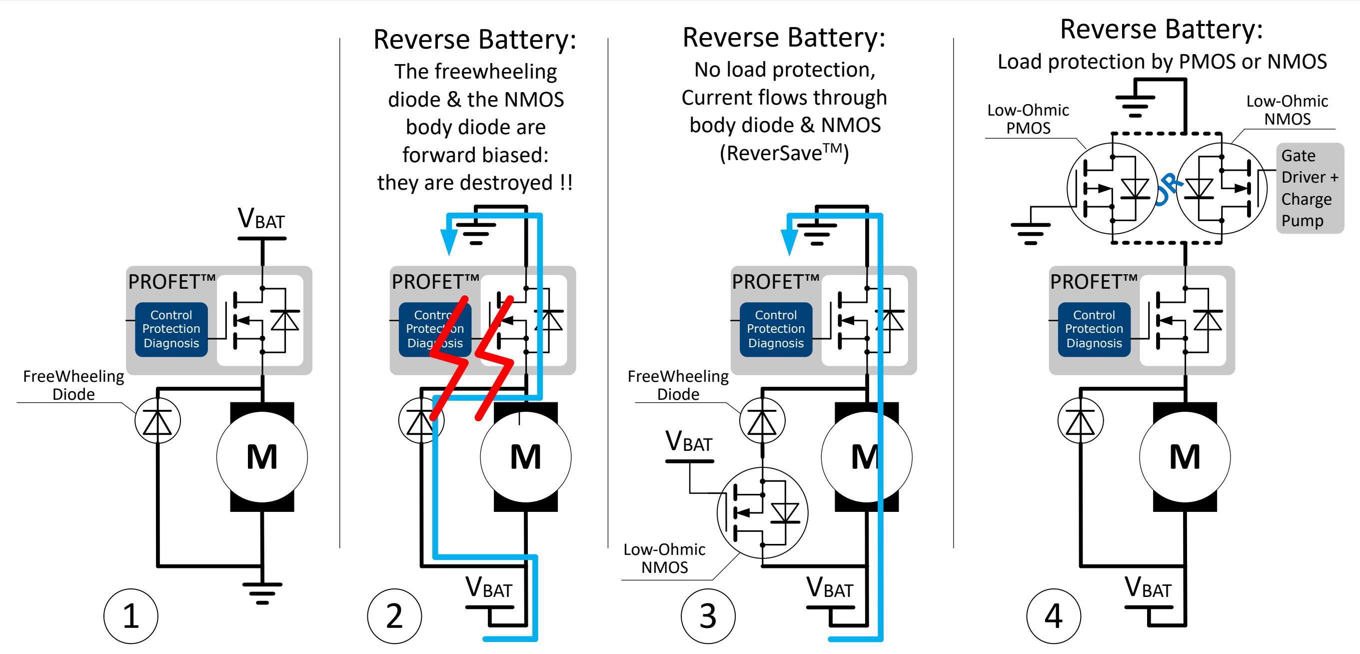


Figure 16 **Reverse battery handling with a smart switch plus a freewheeling diode**

1.5 Diagnosis

Smart switches and relays cannot be compared because relays do not have any diagnosis features.

As described in Protection mechanisms, smart switches come with embedded protection functions. These functions rely on sensing systems, which continuously monitor the MOSFET health.

Very often, the smart switches deliver at least a part of the sensed information to the outside world through dedicated or multiplexed pins. This is a big advantage of smart switches compared to relays. For safety-critical systems, this information enables monitoring the status of the switch and the load. This may also enable some savings on the wiring harness (wire diameter) thanks to a real time monitoring of the current flowing through the cables.

The simplest information provided is a binary/digital signal indicating whether the component is operating correctly, or if it is in a fault mode because it has detected an overstress condition.

1.5.1 Current sense

All the new high-side smart switches provide information on the current sense, which is a current (I_S) equal to a proportion of the load current (I_L):

$$\mathrm{I}_S = \frac{1}{\mathrm{k}_{\mathrm{ILIS}}} \times I_L$$

This information is usually combined with a ‘fault’ status flag. To achieve this combination, the ‘fault’ status flag is converted with a specific current, with a value higher than the maximum sensed current so that the fault flag can be easily differentiated from the sensed current.

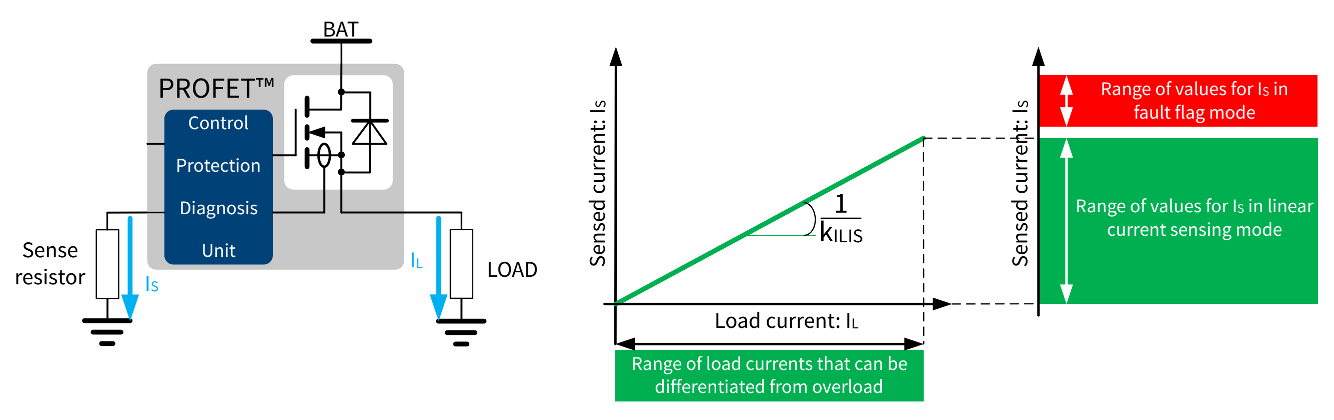


Figure 17 Current sensing feature combined with "fault" status flag

This feature offers a method to interpret the current supplied to the load, in a continuous way. A sense resistor is usually connected to the input of an analog-to-digital converter (ADC) in a microcontroller. It is then possible to monitor the load current and the microcontroller can decide to switch off in case the current is abnormally high but still below the overcurrent threshold. For instance, a rather high ohmic short-circuit from the load to ground, which would increase the current seen by the high-side switch but not trigger the overcurrent protection. This can also be used to build an accurate wire protection algorithm, based on the current flowing through the wire to the load and the duration of the wire/load current.

This feature can also be used to detect if a load is disconnected, when the MOSFET is turned ON. In such a case, the sensed current I_S is zero, or at least in the low end of the current range. This feature is usually called "open load detection in ON".

1.5.2 Open load in OFF

In some applications, it is not appropriate to switch ON the load to perform the open load detection. Some loads immediately start to operate (LEDs, motors) while the sensed current is being evaluated. It is helpful to have a way to detect that the load is disconnected while keeping the MOSFET OFF.

An external pull-up and a voltage comparator (integrated in the smart switch) are used to check if the voltage on the smart switch output is close to ground (load connected) or close to supply (open load).

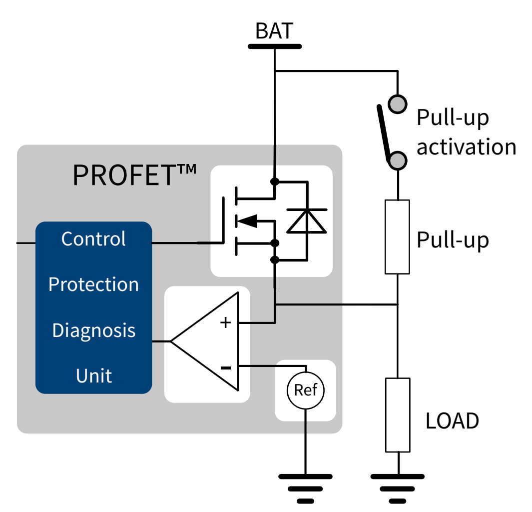


Figure 18 Open load in OFF

The typical value for the comparator reference is 2 V +/-1 V.

The external pull-up is application-specific. Its value depends on the load resistance and any existing current leakage within the application.

1.6 Cross-reference between a relay datasheet and a smart switch datasheet

For users familiar with relay specifications, it is not so straight forward to understand the datasheet from a semiconductor-based smart switch.

Here is a table listing the main parameters found in a relay specification and showing their corresponding parameters in a smart switch datasheet:

Table 1 Typical relay parameters and their corresponding smart switch parameters

Relay parameter	Example (40 A PCB relay)	Smart switch parameter	Symbol	Example (BTS50015-1TAD)1.	Comment
Voltage drop	Typ.: 30 mV (at 10 A) Max.: 300 mV (at 10 A)	ON-state resistance:	$R_{DS(ON)}$	1.5 mΩ (typ. at 135 A and 25°C)	Voltage drop can be easily translated into contact resistance for a comparison to the $R_{DS(ON)}$: 30 mV/10 A = 3 mΩ
Max. continuous current	40 A (at 23°C) 33 A (at 85°C) 22 A (at 105°C)	Nominal load current	$I_{L(NOM)}$	33 A (min. at 85°C)	The nominal load current is highly dependent on the PCB for smart switches: Infineon usually specifies this current for a 4-layer (2s2p) PCB
Max. switching current @ Make	200 A	Current trip detection level	$I_{CL(0)}$	145 A min. at [-40;25]°C 135 A min. at 150°C	Ambient temperature has a slight influence on BTS50015-1TAD, therefore 2 values are specified over the full temperature range
Max. switching current @ Break	40 A (resistive, 13.5 VDC)	Current trip detection level	$I_{CL(0)}$	145 A min. at [-40;25]°C 135 A min. at 150°C	A smart switch can switch ON and OFF the same level of current for non-inductive loads. For inductive loads, there are some limitations at switch OFF
Max. switching voltage	16 VDC	Supply voltage for nominal operation	$V_{S(NOM)}$	[8;18] V	–
Min. contact load	1 A 6 VDC	Not applicable	–	–	A smart switch does not require a minimum load at switch ON/OFF
Electrical endurance	10^5 cycles	–	–	Unlimited	Resistive load
				10^6 (E_{AR})	Inductive load: see datasheet

(table continues...)

Table 1 **(continued) Typical relay parameters and their corresponding smart switch parameters**

Relay parameter	Example (40 A PCB relay)	Smart switch parameter	Symbol	Example (BTS50015-1TAD)1.	Comment
Mechanical endurance	2 x 10^6 OPS	Not applicable	–	–	–
Operate time	Typ.: 4 ms, Max.:10 ms	Turn ON time to V_{OUT} = 90% V_S	t_{ON}	Typ.: 220 µs, Max.: 700 µs	–
Release time	Typ.: 1.5 ms, Max.:5 ms	Turn OFF time to V_{OUT} = 10% V_S	t_{OFF}	Typ.: 300 µs, Max.: 700 µs	–
Ambient temperature	-40°C to 105°C	Junction temperature	T_J	-40°C to 150°C	For a smart switch, the ambient temperature is limited by the max. junction temperature (usually 150°C), the power dissipated by the switch and the type of PCB

2 Impact on the relay box architecture

Over the last thirty years, car manufacturers have been using relays and fuses to build a fail safe power distribution network in the car.

It is common to have two main power distribution boxes in the car:

- Relay box under the hood, to supply high current loads
- Body control module, located inside the cabin, to supply some of the lower to medium current loads inside the car, such as seats control, heating, doors, mirrors control, interior lighting, and front and rear lighting

The following diagram illustrates a common architecture used with relays and fuses:

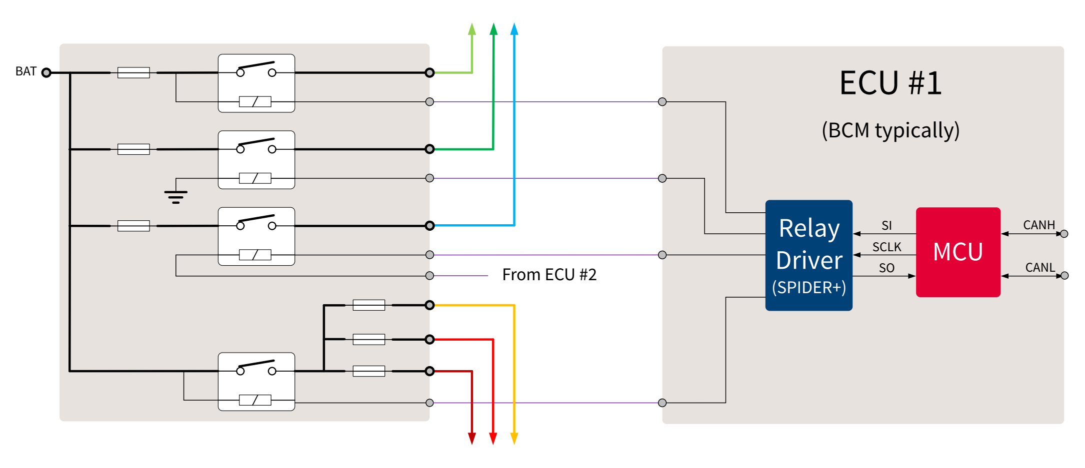


Figure 19 **Example of a relay/fuse box controlled from a remote ECU**

It is visible here that each relay requires an individual wire to control its operating state (ON/OFF).

This diagram is simplified with only 6 different power lines distributed out of the box, but when there are more power lines to manage, there are also more wires to control all the relays. This architecture requires a complex wire harness, which is heavy and expensive.

Once a fuse is melted, it needs to be replaced, which means the relay and fuse boxes must remain accessible. This puts strong constraints on the location of the box and impacts the cable harness length, price, and weight.

Fuses also contribute to wasted power dissipation, because they add a series resistance on the power lines, which generates wasted heat.

In addition, fuses are a valid wire protection, but some of their characteristics lead to oversizing the cables used for the power lines. Fuses exhibit a significant spread of their melting current, which worsens with age. It is then often necessary to oversize a fuse (as compared to the typical load current) to ensure that under all worst case conditions, the fuse does not open with the typical load behavior. Consequently, the cable has to be sized not to the load current, but based on the fuse, which very often leads to using a cable from a higher current range than one that would suit the load current. The cable is then more expensive and heavier.

Another issue faced with fuses is that there may be severe drop downs on the distributed battery voltage if there are hard short-circuits. This results from the fact that fuses are slow to open (in the order of a fraction of a second), which exposes the battery to a high discharge current for a long time, leading to significant voltage drops. In the context of autonomous driving, where several key functionalities, such as fail operational, radars, cameras, and sensor fusion units, must remain active, even during fault conditions, this is not acceptable and another protection mechanism with much faster isolation characteristics is required.

For the reasons listed above, car manufacturers are beginning to migrate power distribution systems from relay/fuse solutions to semiconductor smart switches. Car manufacturers are now in a transition phase where they combine the two solutions inside the power distribution box to optimize the price and the characteristics.

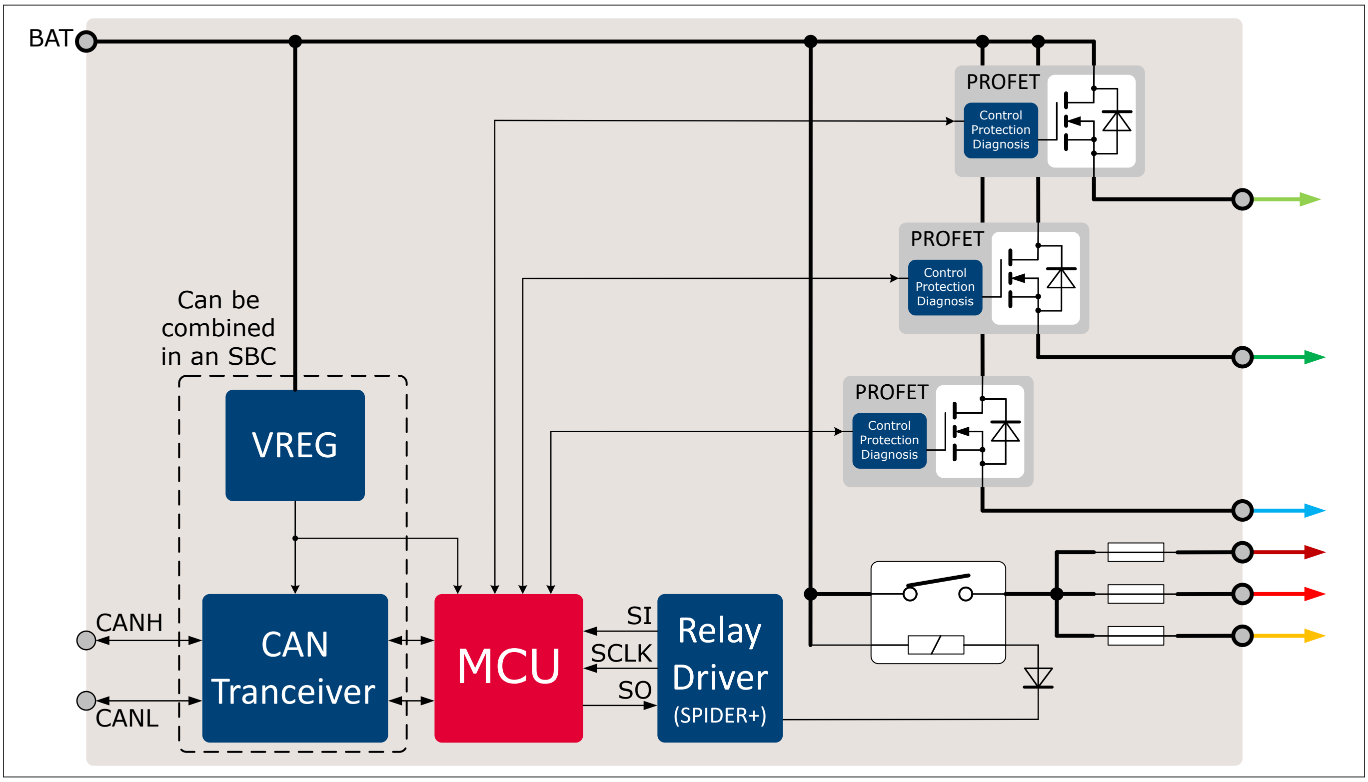


Figure 20 **Example of a mixed relay/fuse/smart switch power distribution box**

One key saving is visible on the cable harness: There are fewer wires to control the box because a serial communication interface is used (CAN here).

To benefit fully from semiconductor smart switches, a further step is to replace all the fuses and relays with a complete smart switch solution.

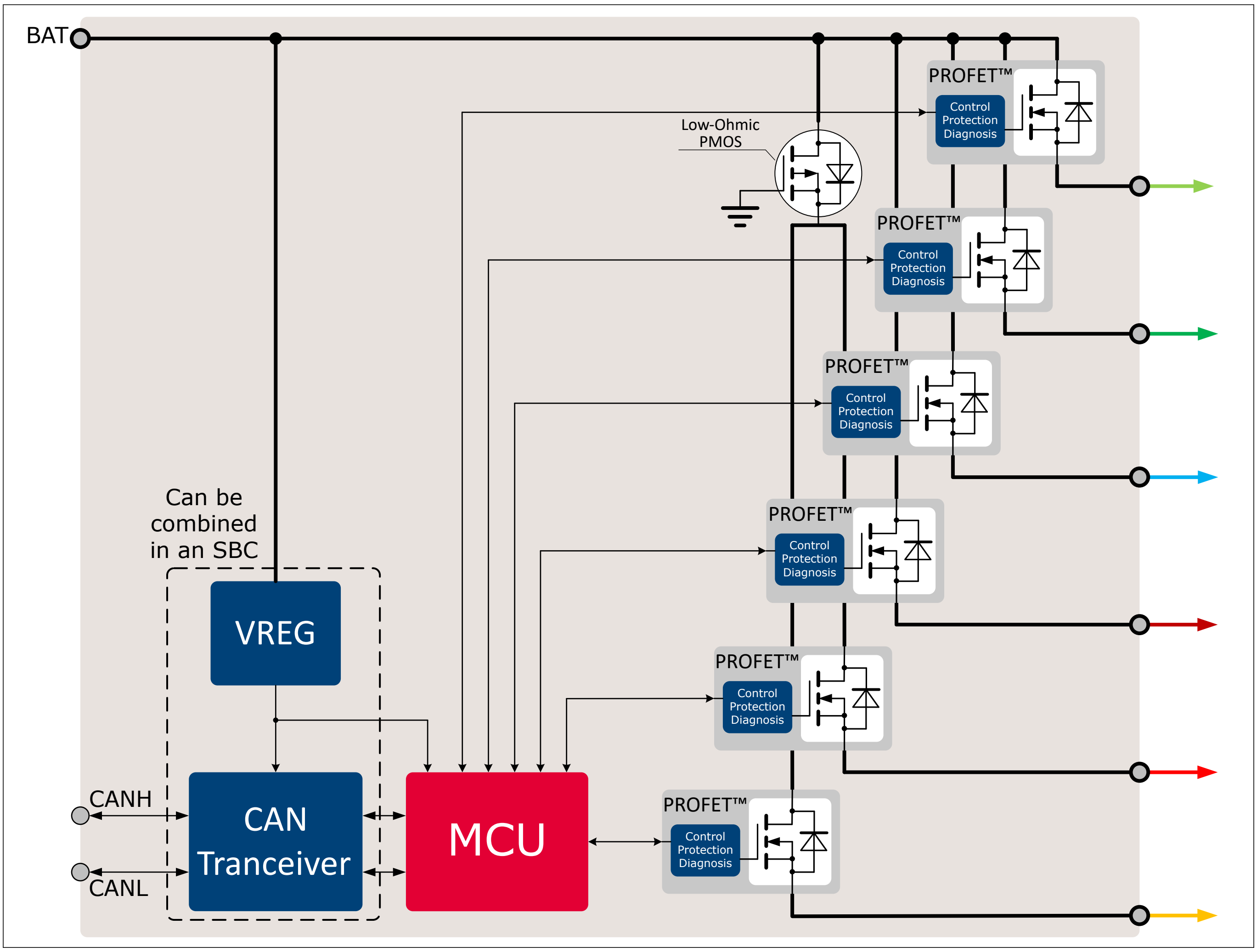


Figure 21 Pure smart switch power distribution box

In such an architecture, all power lines are protected with a very fast overcurrent detection (< 100 µs) and all power lines can be monitored to check the switch health and to optimize the cable diameter.

This architecture makes it possible to spread the power distribution over multiple hubs inside the car, because it is no longer necessary to keep the box easily accessible to replace opened fuses. It is then possible to use a back-bone concept to distribute the battery supply to multiple local smart power distribution boxes, as shown in Figure 22.

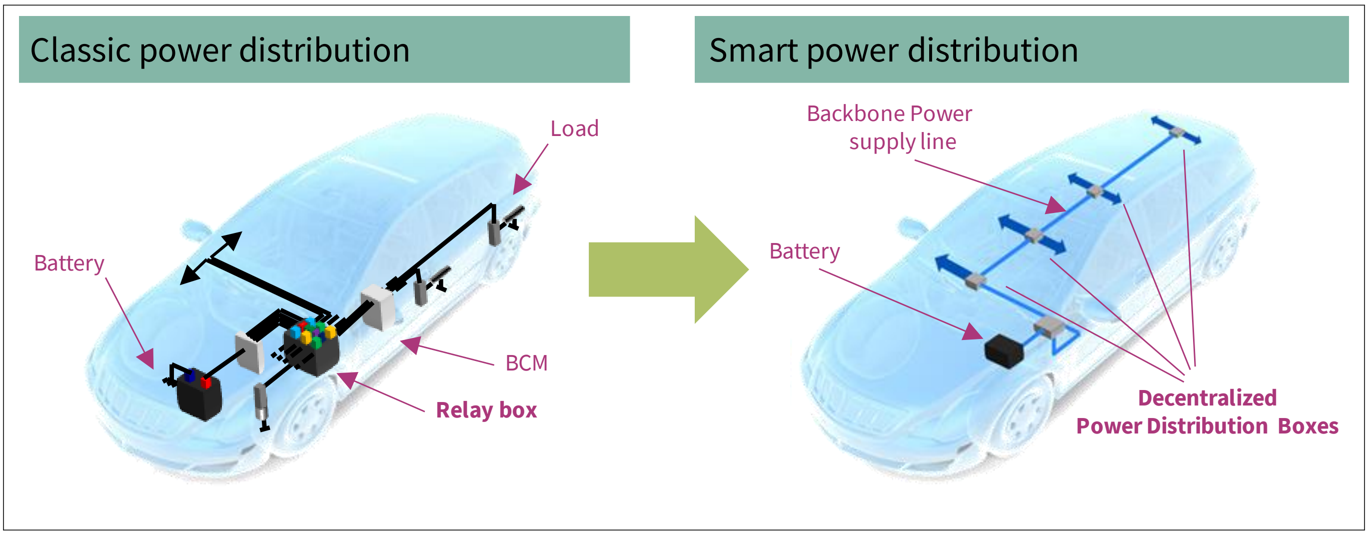


Figure 22 From classic centralized power distribution to distributed power distribution

3 References

1. Datasheet of the BTS50015-1TAD
2. Application Note Z8F65487777: Relay replacement within automotive power distribution. Smart switch basics

4 Glossary and symbols

4.1 Definition of acronyms

Here are the definitions of the main acronyms used in this document:

- ADC: **A**nalog to **D**igital **C**onverter
- BCM: **B**ody **C**ontrol **M**odule
- BJT: **B**ipolar **J**unction **T**ransistor
- DMOS: **D**eep MOS
- ECU: **E**lectronic **C**ontrol **U**nit
- MCU: **M**icro**C**ontroller **U**nit
- PN diode: **P-N** junction diode
- MOSFET: **M**etal **O**xyde **S**emiconductor **F**ield **E**ffect **T**ransistor
- TVS: **T**ransient **V**oltage **S**uppressor

4.2 Symbols

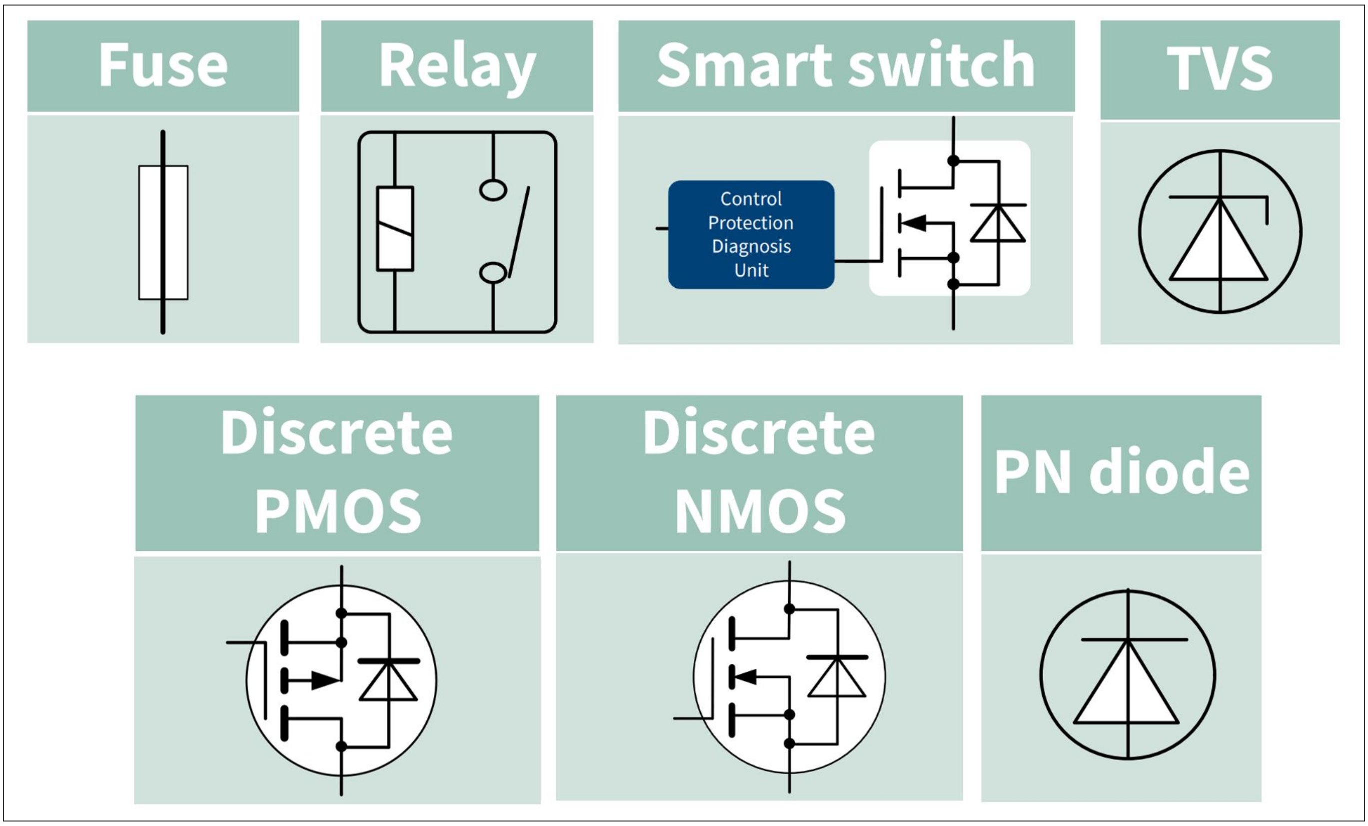


Figure 23 The main symbols used in this document

5 Revision history

Table 2 **Revision history**

Document version	Date of release	Description of changes
Rev. 1.00	2019-05-10	Initial application note
Rev. 1.10	2023-09-12	Updated figures 15, 16, 21, 23. Minor text changes

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