# Relay replacement within automotive power distribution

## Smart switch versus relay: detailed comparison

## About this document

### Scope and purpose

This document intends to give a better understanding of semiconductor-based power distribution in automotive applications. It lists first the key characteristics of the smart switches and then gives a detailed comparison of a smart switch versus an electromechanical relay.

### Intended audience

People familiar with electromechanical relay and fuse based power distribution systems, who want a better understanding of smart power distribution systems based on semiconductor smart switches.

## Table of contents

**Table of contents**

# 1 Smart switch versus relay: detailed comparison

## 1.1 Dimensions, volume and weight

Smart switches clearly outperform relays on the volume/weight characteristics: as it can be seen in **Figure 1**, even the smallest PCB relays are still significantly bigger than smart switches based on D²PAK, DPAK or TDSO-8 packages. Relays are also much heavier: a PCB relay is in the range of 10 g while a smart switch is in the range of 1 g or even below for small packages.
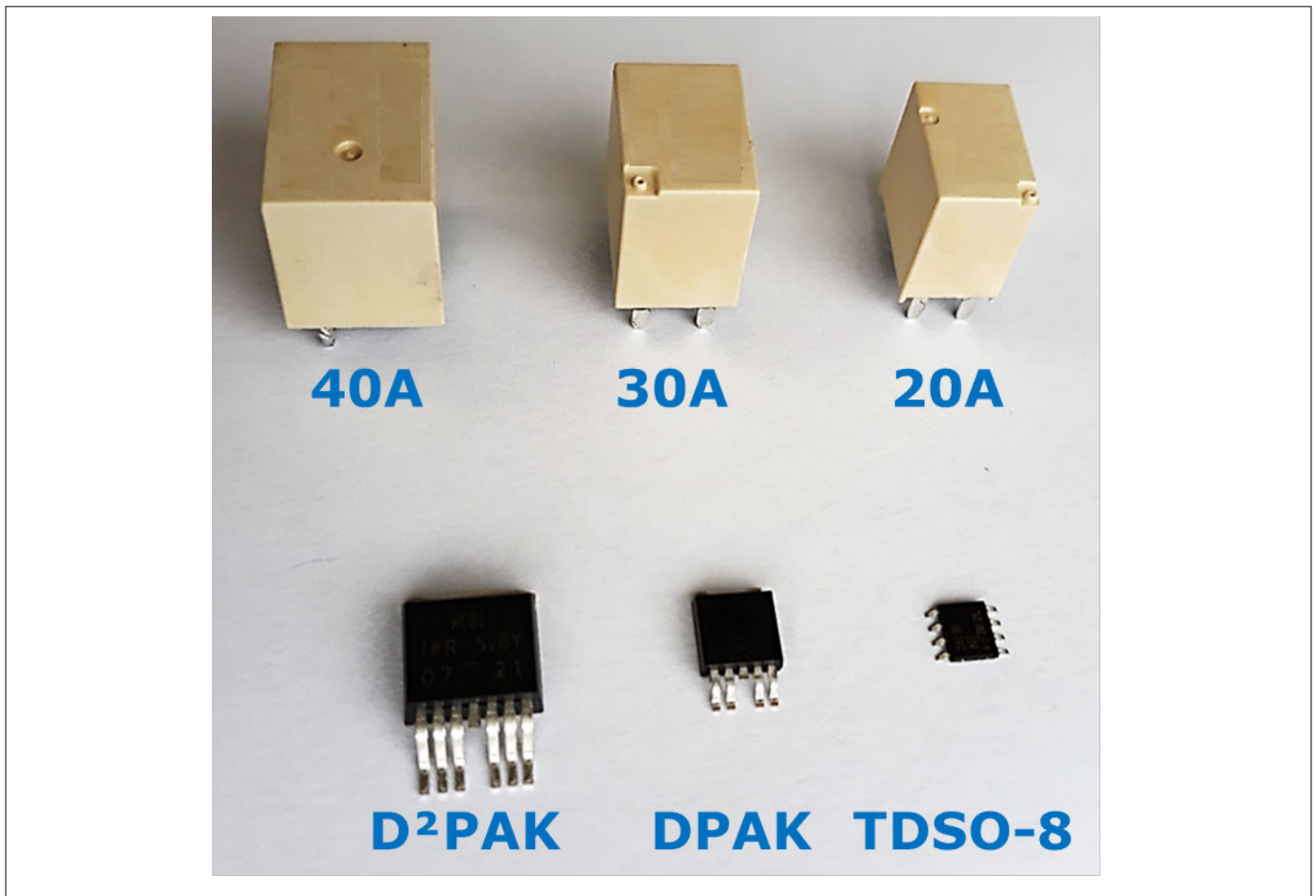


**Figure 1**      Comparison of the size and volume of relays and smart switches

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**1 Smart switch versus relay: detailed comparison**

## 1.2 Power dissipation

### 1.2.1 Relay

There are two contributions 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: $P_{Coil} = V_{BAT}^2/R = 13.5^2/90 =$ **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 $P_{Contact} = R_{Contact} \times I_{Load}^2$

**Figure 2** draws the power dissipated in the relay contact as a function of the load current, from 0 to 30 A.

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

### 1.2.2 Smart switch

The power dissipated inside the smart switch also has two contributions:

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

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

### 1.2.3 Graphic comparison

**Figure 2** plots the total power dissipation for the relay and for the smart switch: it is visible 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 or Sleep mode, then the smart switch power dissipation scales with the current and comes to very low values, unlike the relay which still dissipates around 2 W.
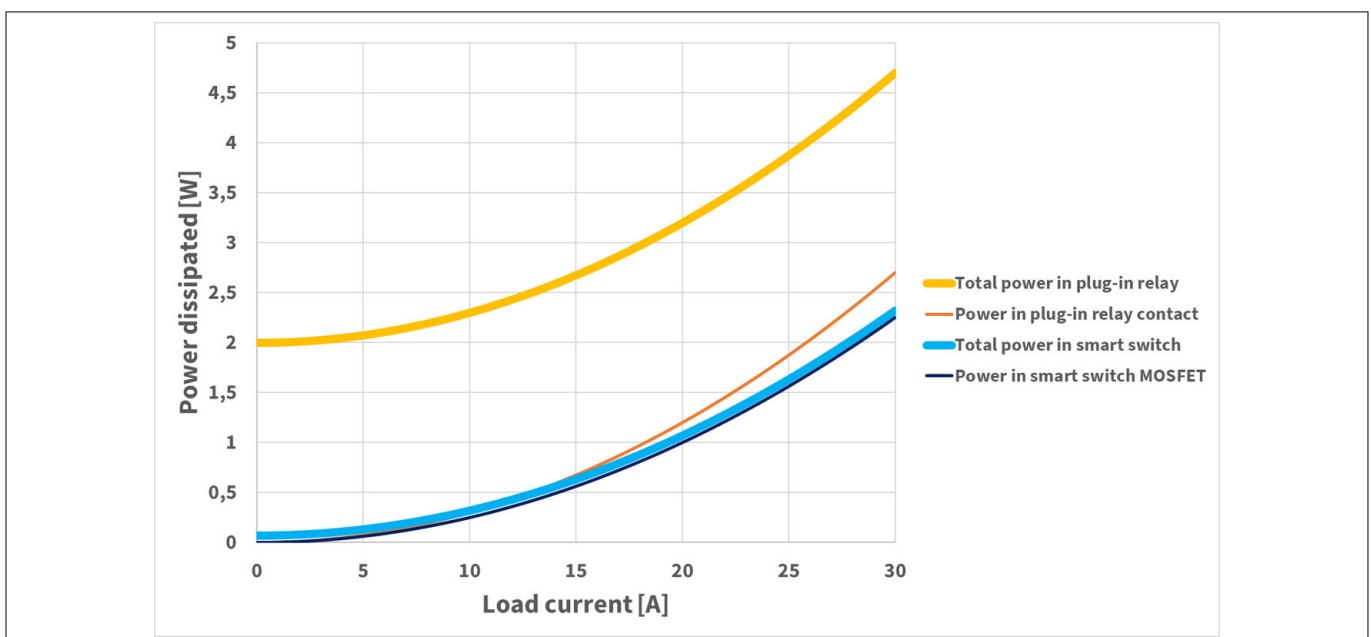


**Figure 2**        Comparison of the power dissipation in a relay versus a smart switch

## 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 Electro-Magnetic 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 operate voltage (6 V typically) up to 5 bounces when 13.5 V is applied on the coil.

*Figure 3* illustrates the bouncing behavior when 12 V is applied on the coil: here 3 bounces are visible.
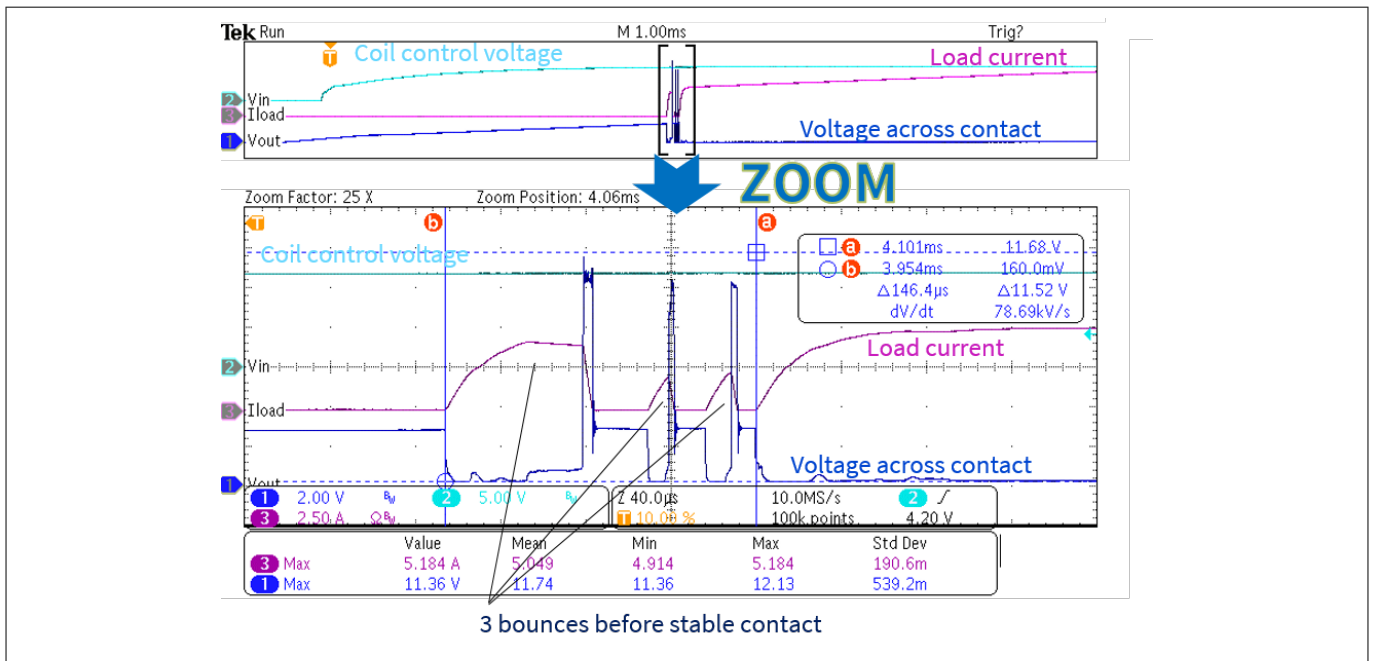


**Figure 3**        **Contact bouncing visible on current and voltage waveforms (switch ON)**

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 on *Figure 4* below.

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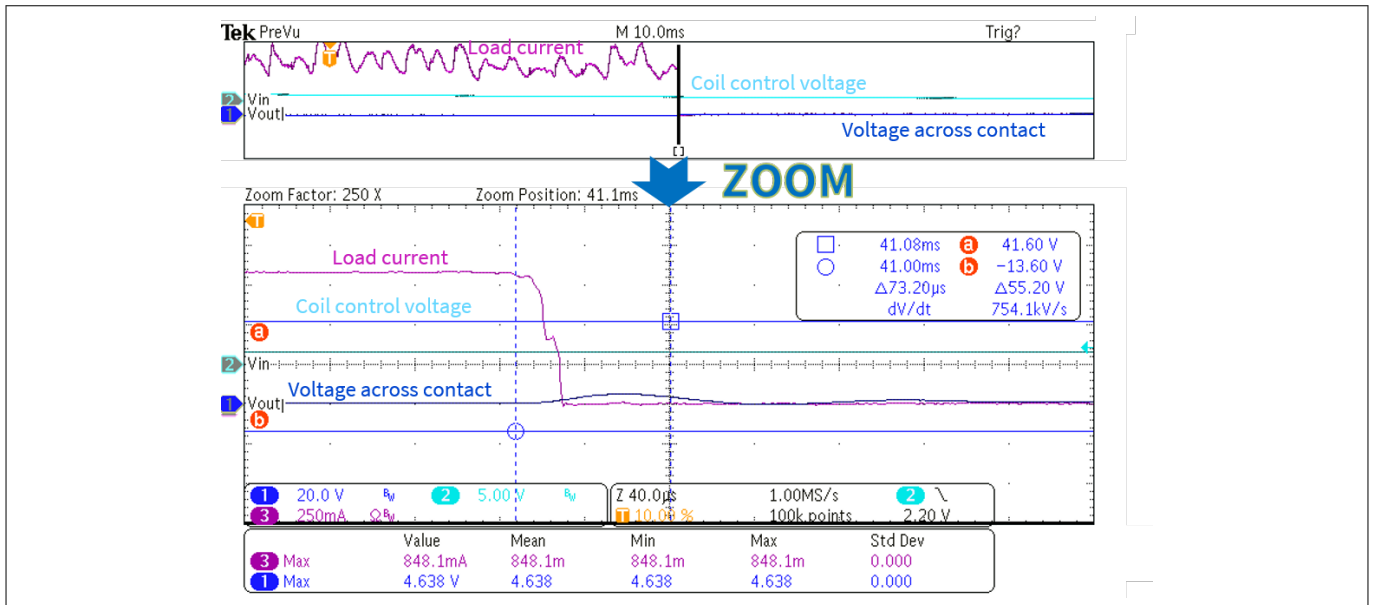**1 Smart switch versus relay: detailed comparison**



**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 on **Figure 5**.
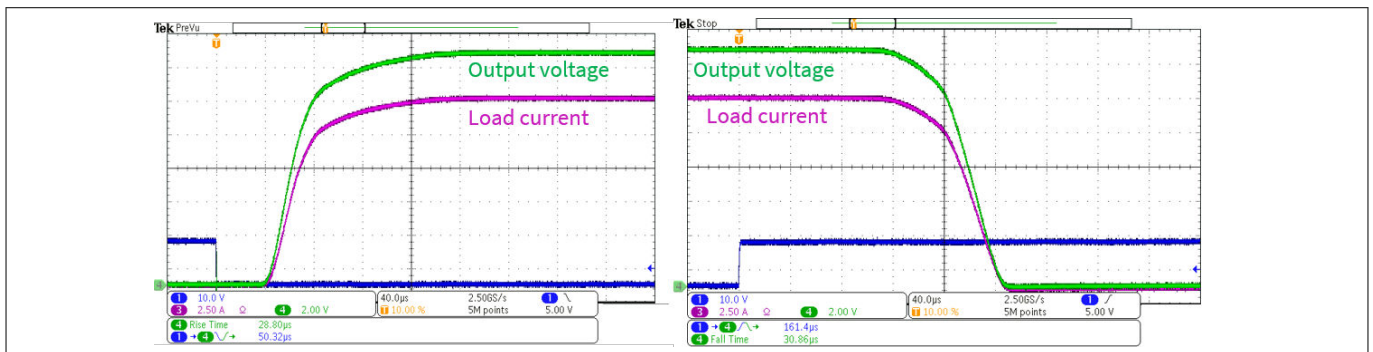


**Figure 5**          **Example of the switching waveforms with a 12 V automotive smart switch**

## 1.3.2          Dry switching

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

In order to ensure a long lifetime of the relay, manufacturers strongly recommend to avoid "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 (more details in **Chapter 1.3.4**). These minimum and maximum current at operate and release are provided in the Relay datasheets.

Dry switching is not a concern for smart switches: their capability here is in the range of $10^{15}$ cycles. Therefore, 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

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**1 Smart switch versus relay: detailed comparison**

- Incandescent bulbs
- ECUs (Electronic Control Units) with filtering capacitance on their supply terminal. The ECUs could be driving DC motors or ADAS features (camera, radar etc.)
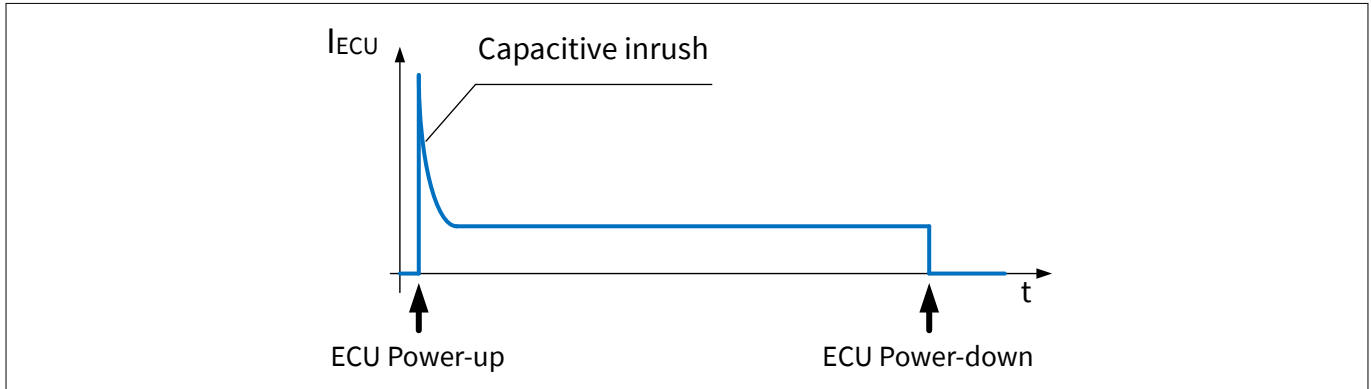


**Figure 6**      **Current profile of an ECU load with inrush at power on**

The contact inside a relay is sensitive to the inrush current. Indeed, the bouncing generates a sequence of closing/opening of the contact. When opening the contact, arcing may 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 arching but the inrush current is a stress which 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 (see more details in ***Chapter 1.4.1***).

To properly select the smart switch, 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. See more details in ***Chapter 1.4.1***
- Dynamic thermal response. See more details in ***Chapter 1.4.2***

## 1.3.4      Robustness when exposed to inductive demagnetization

Several types of loads 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 mandatory to invert the voltage polarity applied on the inductor, as shown on ***Figure 7***:

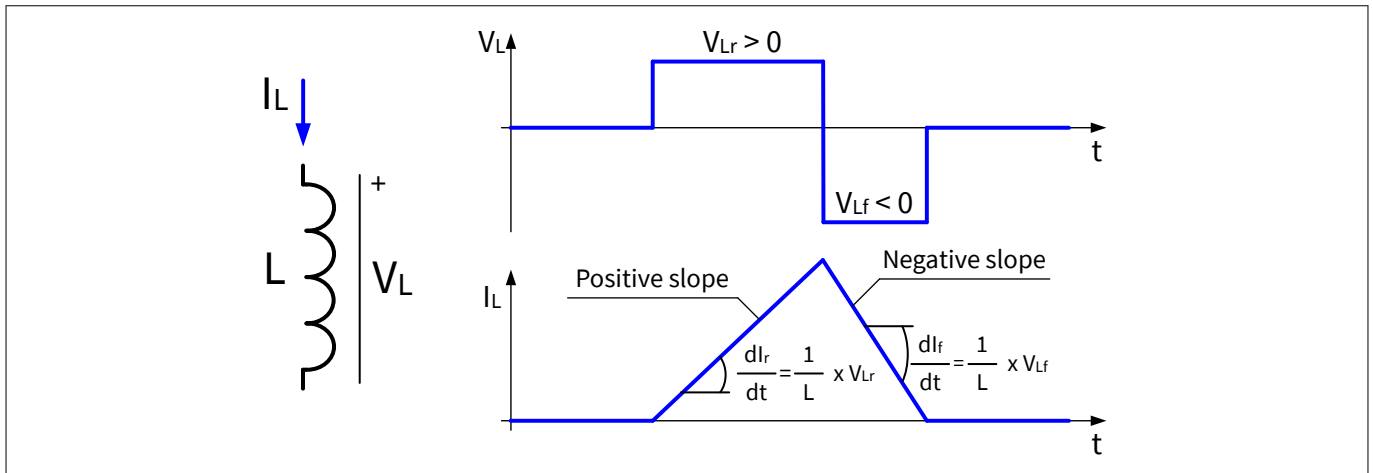## 1 Smart switch versus relay: detailed comparison



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

The consequence is that it is mandatory to apply a negative voltage across the inductance in order 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 hundreds of 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 may damage the contact surface and jeopardize the relay lifetime. Relay vendors recommend in such a case to use external clamping components (freewheeling diodes, Transient Voltage Supressors, TVS) to protect the relay contact.
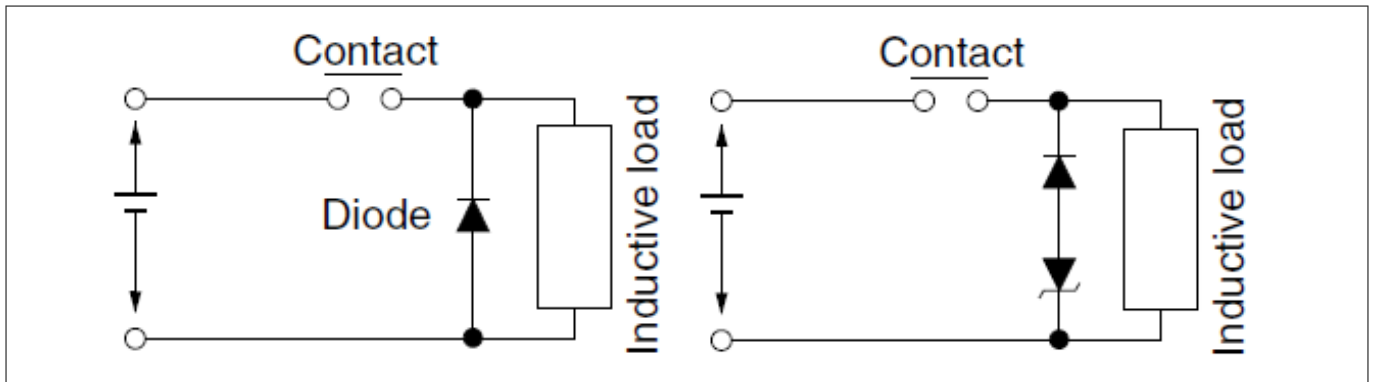


**Figure 8**     **Example of protection circuitries for relays driving inductive loads**

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 $V_{DS(CL)}$ is the clamping voltage across the power MOSFET within the smart switch. It behaves very similar to a zener diode. Since $V_{DS(CL)}$ is more than two times larger than $V_{BAT}$, $V_L$ is negative:

**1 Smart switch versus relay: detailed comparison**
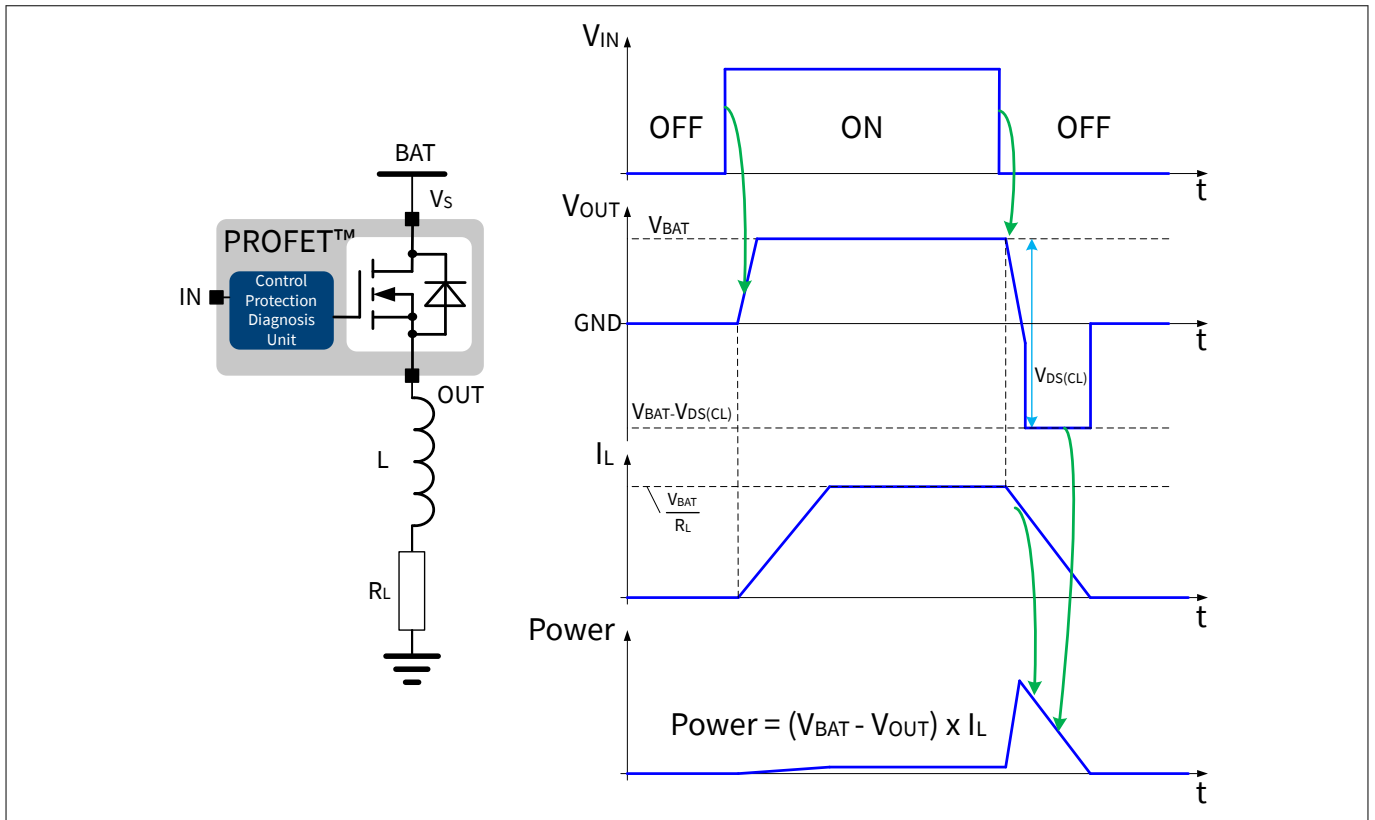


**Figure 9** **Voltage and current waveforms during an inductor demagnetization**

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 a thermal stress which can be handled by the smart switch or not. So similar to relays, it may be necessary to use external clamping components (freewheeling diodes and Transient Voltage Supressors; TVS) to protect the smart switch from strong demagnetizations.
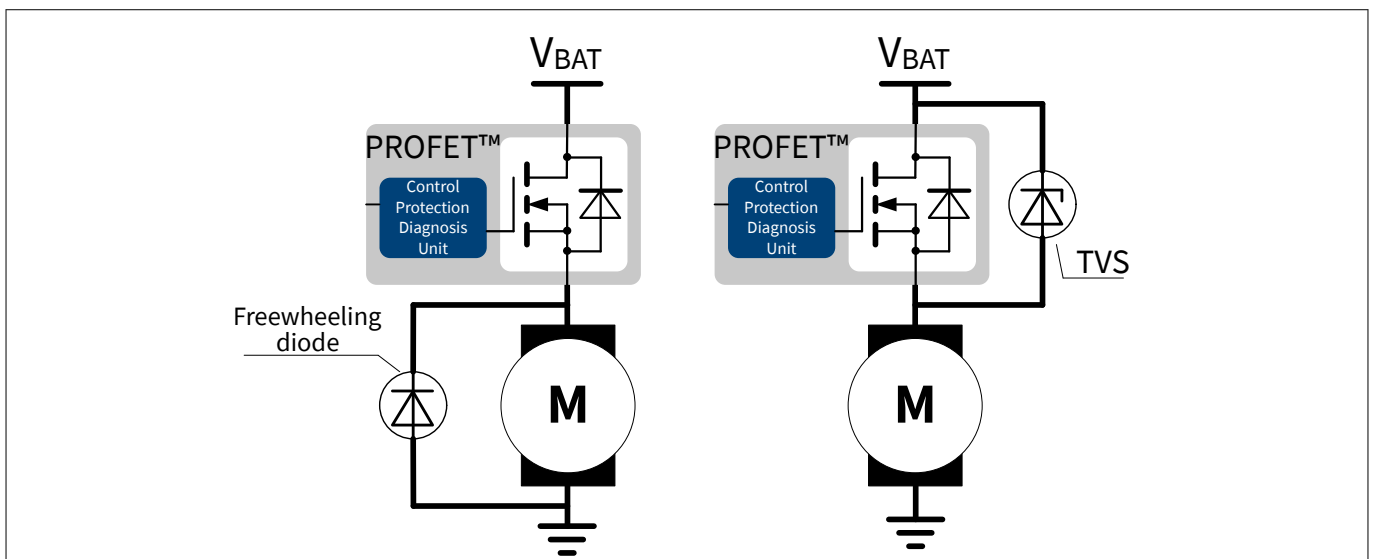


**Figure 10** **Example of protection circuitries for smart switches driving inductive loads**

## 1.3.5 Switching cycles

Relays datasheets usually reference the electrical and mechanical endurance, since there is a limited number of operate/release cycles allowed. In general, the mechanical endurance is better than the electrical endurance, in the range of a million cycles for the first one and in the range of a hundred thousands for the second one.

Electrical endurance is not straightforward to assess for relays: it is highly dependent on the load characteristics. Relay manufacturers usually specify a number of activations for a specific load with a specific activation profile (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 will exhibit a better electrical endurance than a 20 A relay. But it comes with a higher cost also.

For loads which 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 *Chapter 1.3.2*. The only limitation which 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. Smart switches datasheets 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 the previous section (*Chapter 1.3.4*).

## 1.4 Protection mechanisms

On top of several others, there are three main conditions where the MOSFET inside the smart switch may be jeopardized in the application:

- Over current (mainly happening in case of load short circuits)
- Overtemperature
- Reverse battery

These three conditions are detailed in the following sections.

## 1.4.1 Overcurrent protection

Both a relay and a smart switch are in danger when they are exposed to a high current.

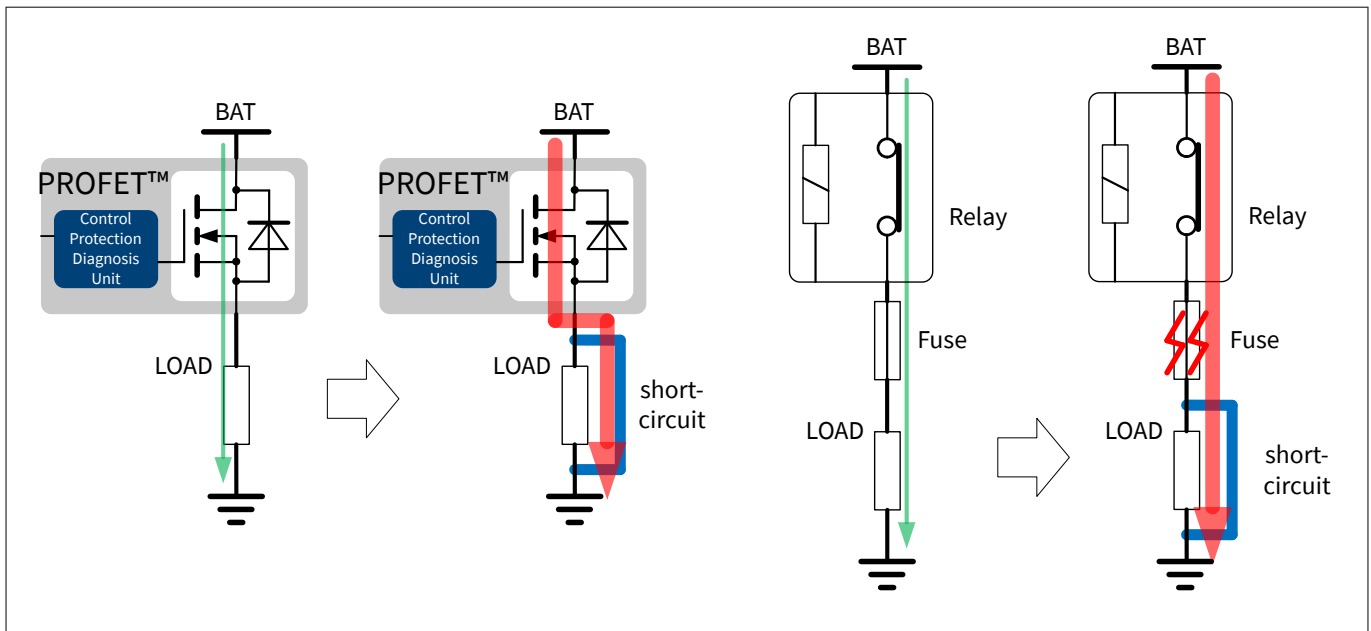The most common condition is when the load is short-circuited:



**Figure 11        Overcurrent in case of a load short-circuit condition**

The relay has no internal protection against overcurrent. It has to rely on an external protection which is usually fuse-based: when exposed to a high current, the fuse melts and opens such 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 to a reference threshold. When the current is above this reference, the MOSFET is usually switched OFF.

Some smart switches do not immediately switch OFF, they rather move to a current limitation mode, where the MOSFET delivers a smaller/limited current to the load. For such smart switches, the final/ultimate protection is the overtemperature protection since 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: there are no parts to replace.
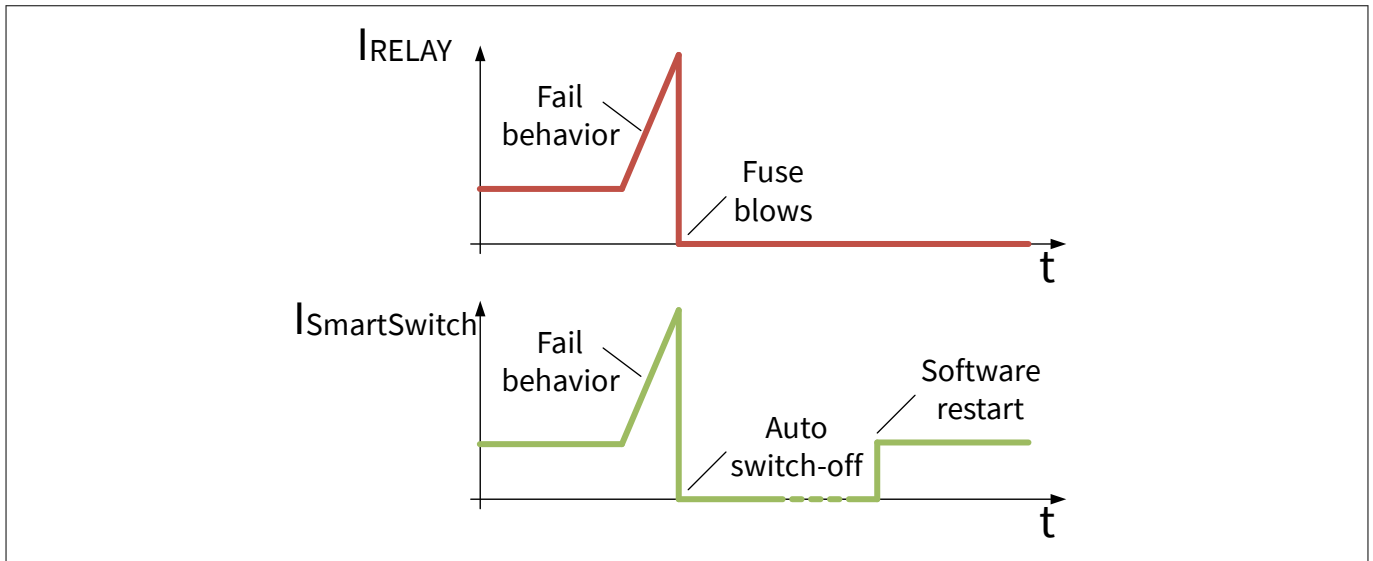
**1 Smart switch versus relay: detailed comparison**



**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 will be damaged.

For the relay, there are 3 contributors 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 ($R_{Contact} \times I_{Load}^2$)
- The ambient temperature outside the case of the relay

Some relay manufacturers indicate in their datasheets what is the internal temperature increase for various coil voltages applied (impacting the power dissipated in the control coil) and various currents flowing through the contact (impacting the power dissipated in the contact). See **Figure 13**.
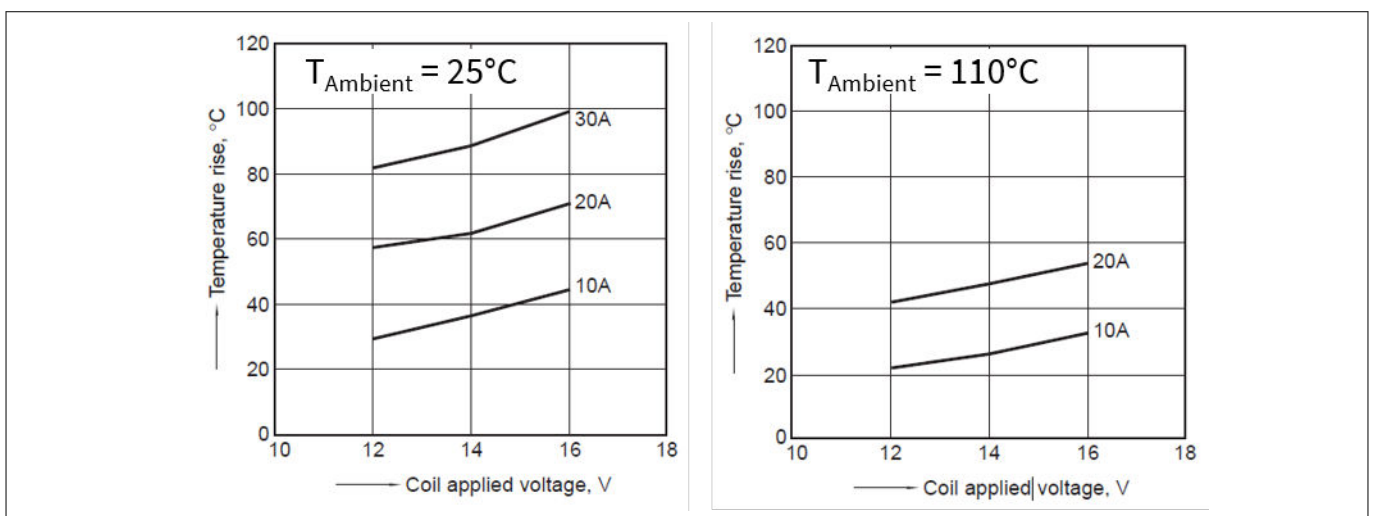


**Figure 13**          **Temperature rise inside a relay, $I_{LOAD}$ = 30 A not possible at $T_{Ambient}$ = 110°C (right)**

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, there are 3 contributors to the internal temperature:

- The power dissipated in the control circuit ($V_{Bat} \times I_{Operating}$)

- 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 seen in **_Chapter 1.3.4_**
- The ambient temperature outside of the package of the smart switch

The first contributor can be neglected in general: the power dissipated by the control circuit driving the power MOSFET is below 50 mW in general, so it is a small contributor.

The main contributor is the power dissipated in the power MOSFET. In some conditions, the MOSFET may be 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 temperature which may damage it.

The internal protection control circuitry is continuously sensing the MOSFET temperature and may switch it OFF if its absolute temperature becomes too high. In such a case, the power dissipated inside the MOSFET (and thus also MOSFET temperature) immediately comes down, protecting the device from destructive failure and the system from overload.

## 1.4.3 Reverse battery protection

Car manufacturers usually mandate that a reverse battery polarity connection does not destroy anything in the vehicle.

For some loads, reverse polarity is not an issue: they are insensitive to the voltage polarity. A typical example of such loads is a windshield defroster: such a heating resistance will generate some heat whatever the voltage polarity 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 since it will force the pump to run backwards.

When a relay is used to switch the power supply of a load, the reverse battery protection is quite straightforward: considering a Normally Open (NO) relay driving a motor, the coil driver usually has a body diode since they are most commonly based on MOSFETs (for more details on this, you can refer to the first chapter of **_[2]_**). Scenario (1) on **_Figure 14_** illustrates such a configuration based on a low side smart switch which is part of the HITFET™ family, from Infineon.

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) on **_Figure 14_**).

If the load can be damaged in such a configuration, a low cost small signal diode (1N4148 for instance) 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 in the load, so it is safe. This is illustrated in scenario (3) on **_Figure 14_**.

As a summary, with a relay only the coil control path may have to be blocked with a diode. This is fortunately a low current path, which allows to use a low cost small signal diode.
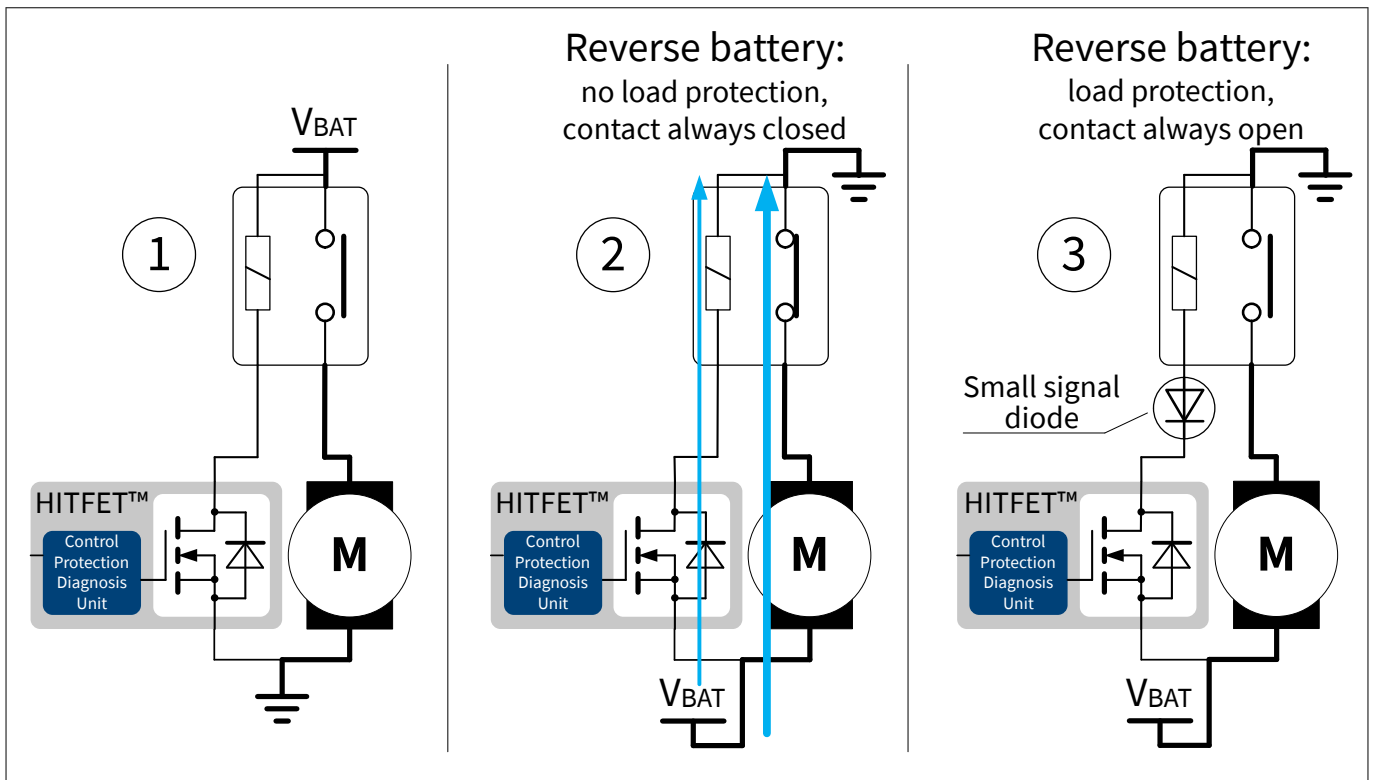
**1 Smart switch versus relay: detailed comparison**



**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. Indeed, the MOSFET body diode allows the current to flow through the load during battery polarity reversal. A rough calculation (considering a 5 mΩ $R_{DS(ON)}$ on smart switch) shows that the power losses are unfortunately much higher when the current flows through the diode than when it flows through the MOSFET itself:

- Power losses in the diode: $P_{Diode} ≈ 1$ V x $I_{Motor}$. If $I_{Motor} = 20$ A --> $P_{Diode} ≈$ **20 W**
- Power losses in the NMOS: $P_{NMOS} = R_{DS(ON)}$ x $I_{Motor}^2$. If $I_{Motor} = 20$ A and $R_{DS(ON)} = 5$ mΩ --> $P_{NMOS} =$ **2 W**

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

This protection only applies to the MOSFET, not to the load itself. Indeed, the load is still exposed to the battery voltage/current, in reverse polarity, which may be an issue. If the load requires a protection, it is necessary to add a diode function as a blocker on 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 on *Figure 15*, scenario (3):

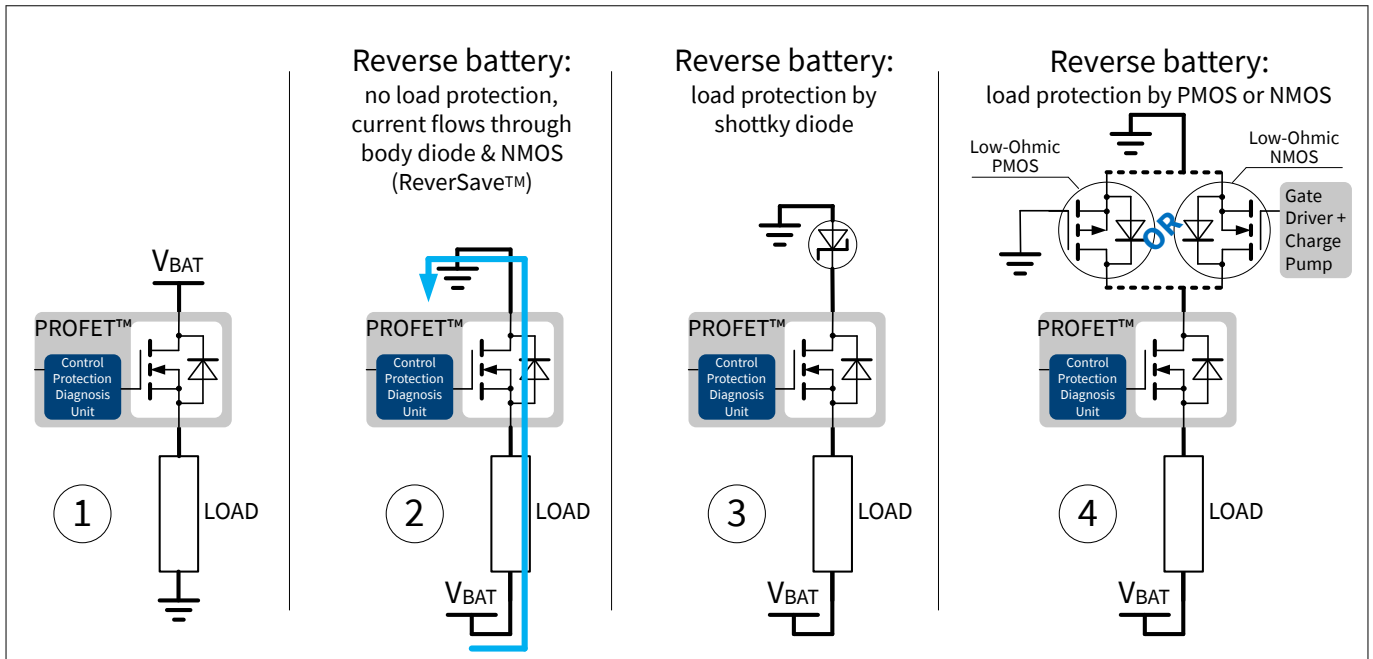## 1 Smart switch versus relay: detailed comparison



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

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

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

- Either 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 in case of wrong battery polarity
- Or an NMOS together with a gate driver including a charge pump, to generate a gate voltage higher than the battery voltage when the battery polarity is correct. Infineon offers a family of components, called SBC Lite (SBC = System Basis Chips), which embed several building blocks including a charge pump which can be used to drive such a reverse block NMOS

Additional scenarios have to be considered if the load is highly inductive and the smart switch has to be protected against inductive demagnetizations with additional external components. This is especially necessary when a freewheeling diode is used: a reverse blocker is absolutely mandatory since the freewheeling diode and the smart switch form a circuit with two series diodes which allow virtually unlimited current to flow when exposed to reverse polarity (scenario (2) on **Figure 16**). For the 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 in case of wrong battery polarity. See scenario (3) on **Figure 16**
- The load cannot be exposed to the reverse battery: the protection scheme is the same as the one used in scenario (3) on **Figure 15**. See scenario (4) on **Figure 16**

**1 Smart switch versus relay: detailed comparison**



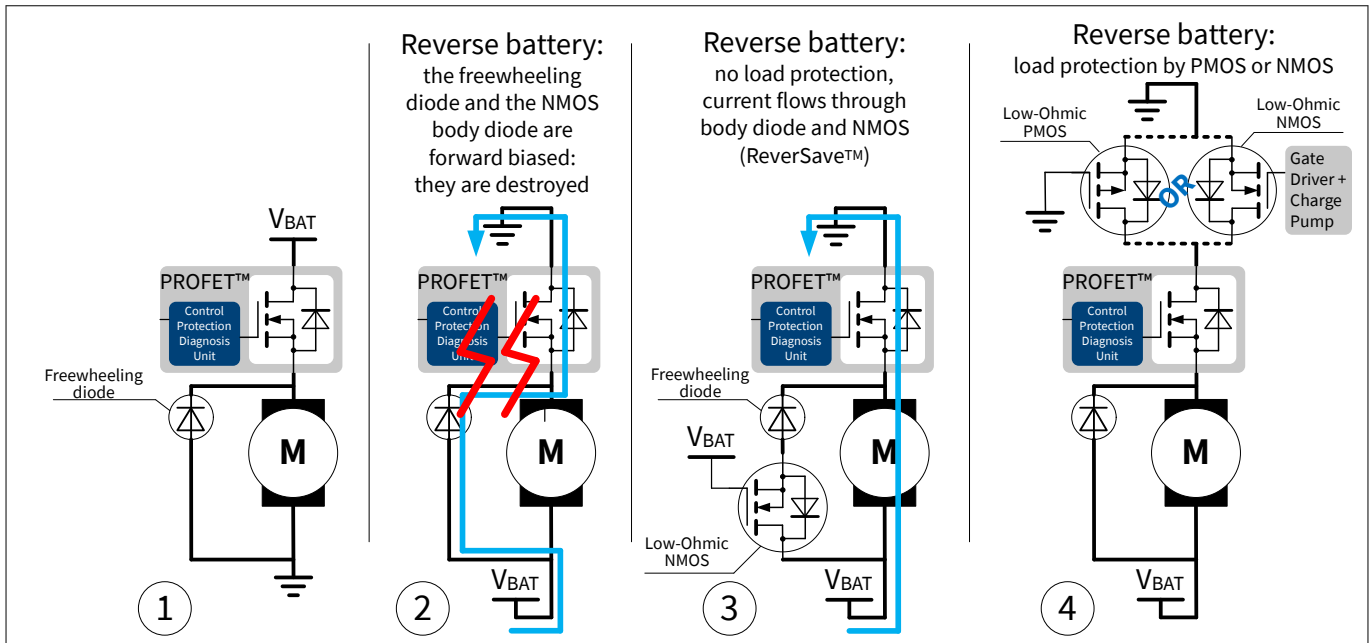**Figure 16**          **Reverse battery handling with a smart switch plus a freewheeling diode**

## 1.5          Diagnosis

Here smart switches and relays cannot be compared: relays simply do not have any diagnosis features.

As seen in the previous section (**Chapter 1.4**), 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 strong added value of smart switches compared to the relays: for safety critical systems, this allows to monitor 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 if the component is in a healthy operation or if it is in a fault mode due to the detection of an overstress condition. The next sections detail other diagnostic methods which are also provided by some of the smart switches.

## 1.5.1          Current sense

All the new High Side smart switches provide a current sense information, which is a current ($I_S$) equal to a proportion of the load current ($I_L$):

$$I_S = \frac{1}{k_{ILIS}} \times I_L$$

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.
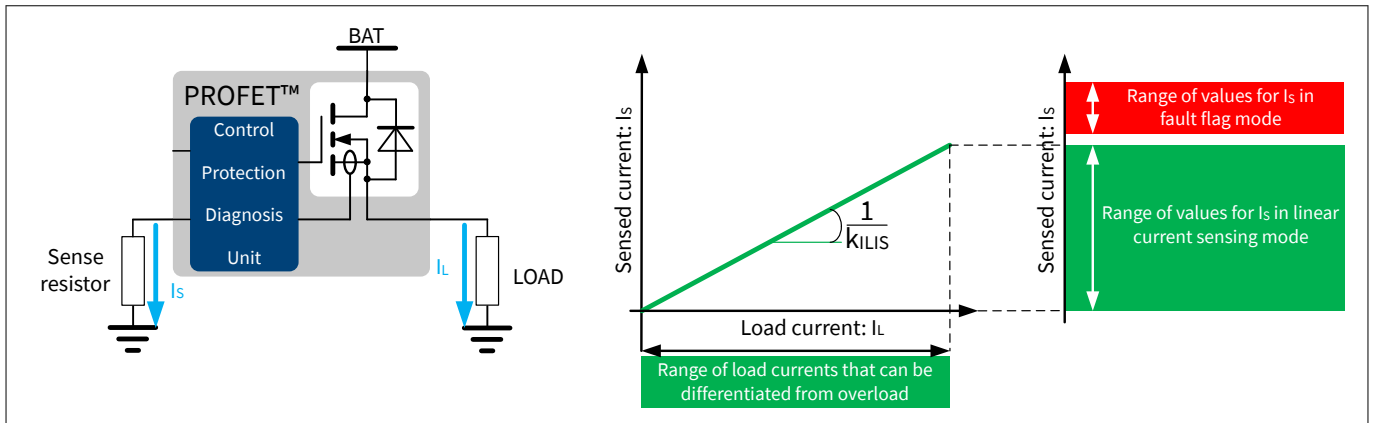
## 1 Smart switch versus relay: detailed comparison



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

This feature allows 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 may not be appropriate to switch ON the load to perform the open load detection: some loads will immediately start to operate (LEDs, motors) while the sensed current is being evaluated. It can thus be useful then 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).
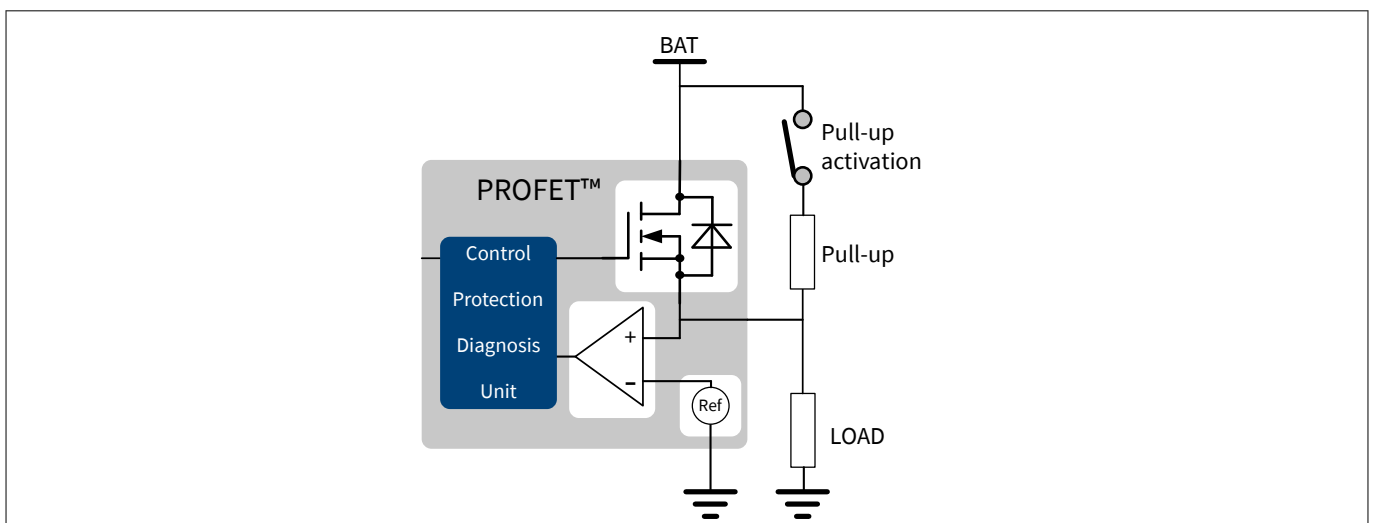


**Figure 18**      **Open load in OFF**

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

**1 Smart switch versus relay: detailed comparison**

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

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

Being familiar with relay specifications, it is not so straight forward to look at 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 relays parameters and their corresponding smart switch parameters**

| Relay parameter | Example (40 A PCB relay) | Smart switch parameter | Symbol | Example (BTS50015-1T AD)[1] | Comment |
|---|---|---|---|---|---|
| Voltage drop | Typ.: 30 mV (at 10 A)<br>Max.: 300 mV (at 10 A) | ON-State resistance: | $R_{DS(ON)}$ | 1.5 mΩ<br>(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)<br>33 A (at 85°C)<br>22 A (at 105°C) | Nominal Load Current | $I_{L(NOM)}$ | 33 A<br>(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<br>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<br>135 A min. at 150°C | A smart switch can switch ON and OFF the same level of current, for non-inductive loads.<br>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 |
| Mechanical endurance | $2 \times 10^6$ OPS | Not applicable | – | – | – |

## 1 Smart switch versus relay: detailed comparison

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

| Relay parameter | Example (40 A PCB relay) | Smart switch parameter | Symbol | Example (BTS50015-1T AD)[1] | Comment |
|---|---|---|---|---|---|
| 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, the 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 lower/medium current loads inside the car (seats control/heating, doors/mirrors control, interior lighting, front and rear lighting etc.)

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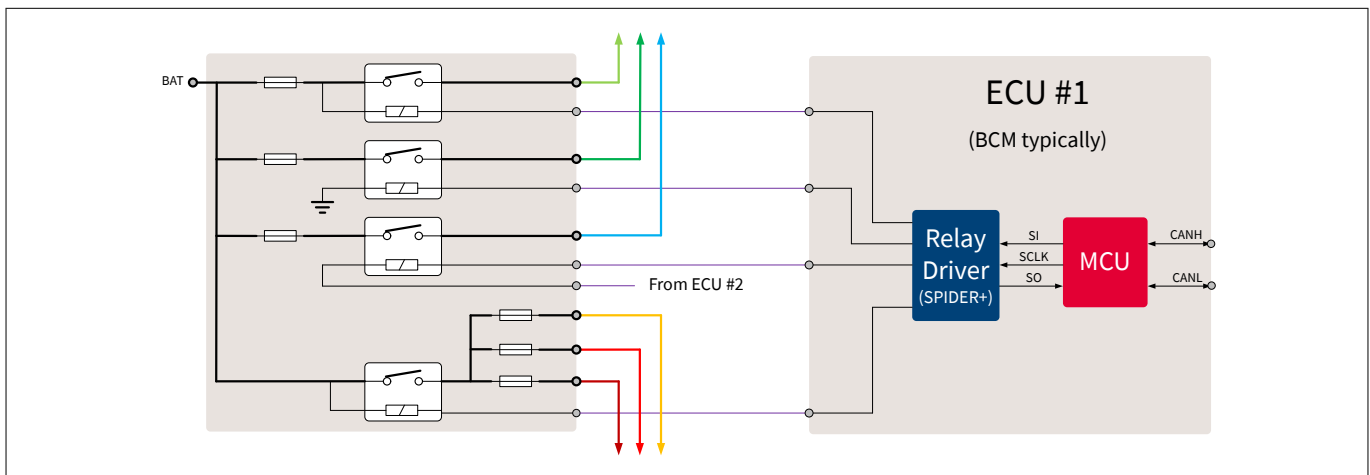


**Figure 19**      **Example of a relay/fuse box controlled from a remote ECU**

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 open/melted, it needs to be replaced, which implies to keep the relay and fuse boxes 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, since 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: indeed, fuses exhibit a significant spread of their melting current, which becomes even worse with aging. It is then often required to oversize a fuse (as compared to the typical load current) in order to ensure that under all worst case conditions the fuse will not open with the typical load behavior. Thus then, the cable has to be sized not to the load current, but based on the fuse, which very often leads to use a cable from a higher current range than the one which would fit with 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 in case of hard short-circuits. It comes 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 scope of autonomous driving where several key functionalities have to remain active even during fault conditions (fail operational: radars, cameras, sensor fusion unit etc), 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. They are now in a transition phase where they combine the two solutions inside the power distribution box, to optimize the price and the characteristics:

## 2 Impact on the relay box architecture
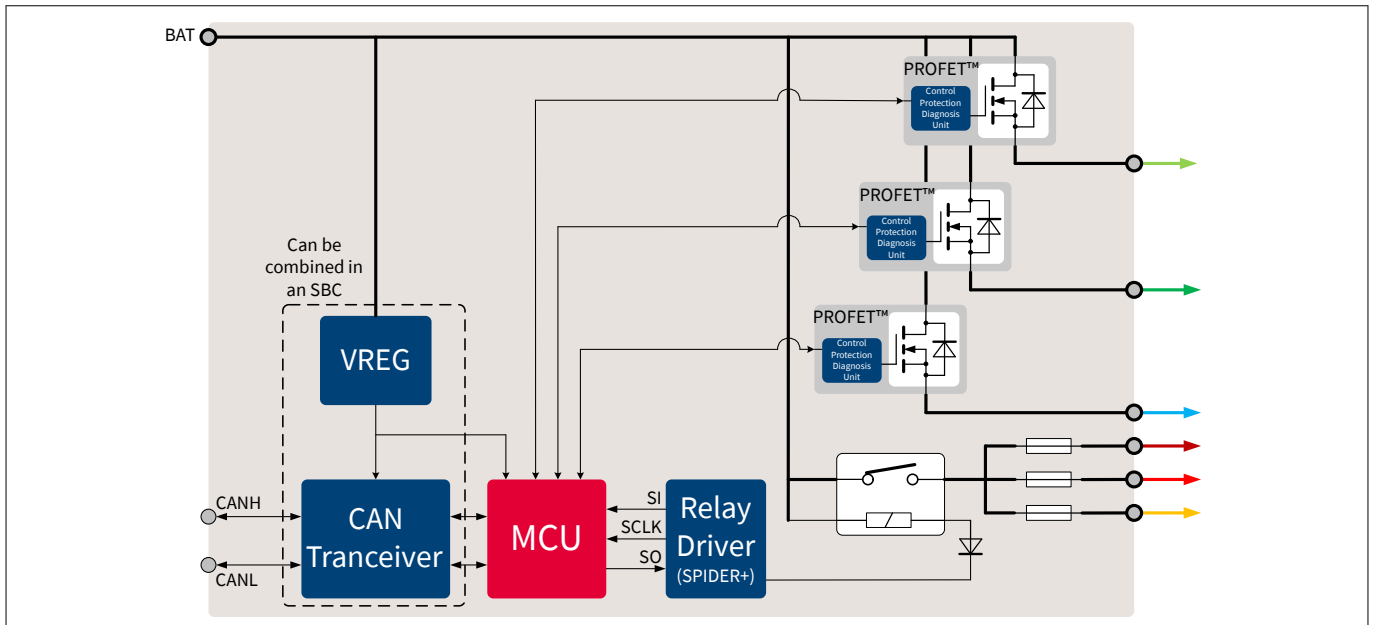


**Figure 20          Example of a mixed relay/fuse/smart switch power distribution box**

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

To get the full benefit from the semiconductor smart switches, a further step would be to remove all the fuses and relays and thus have a complete smart switch solution:
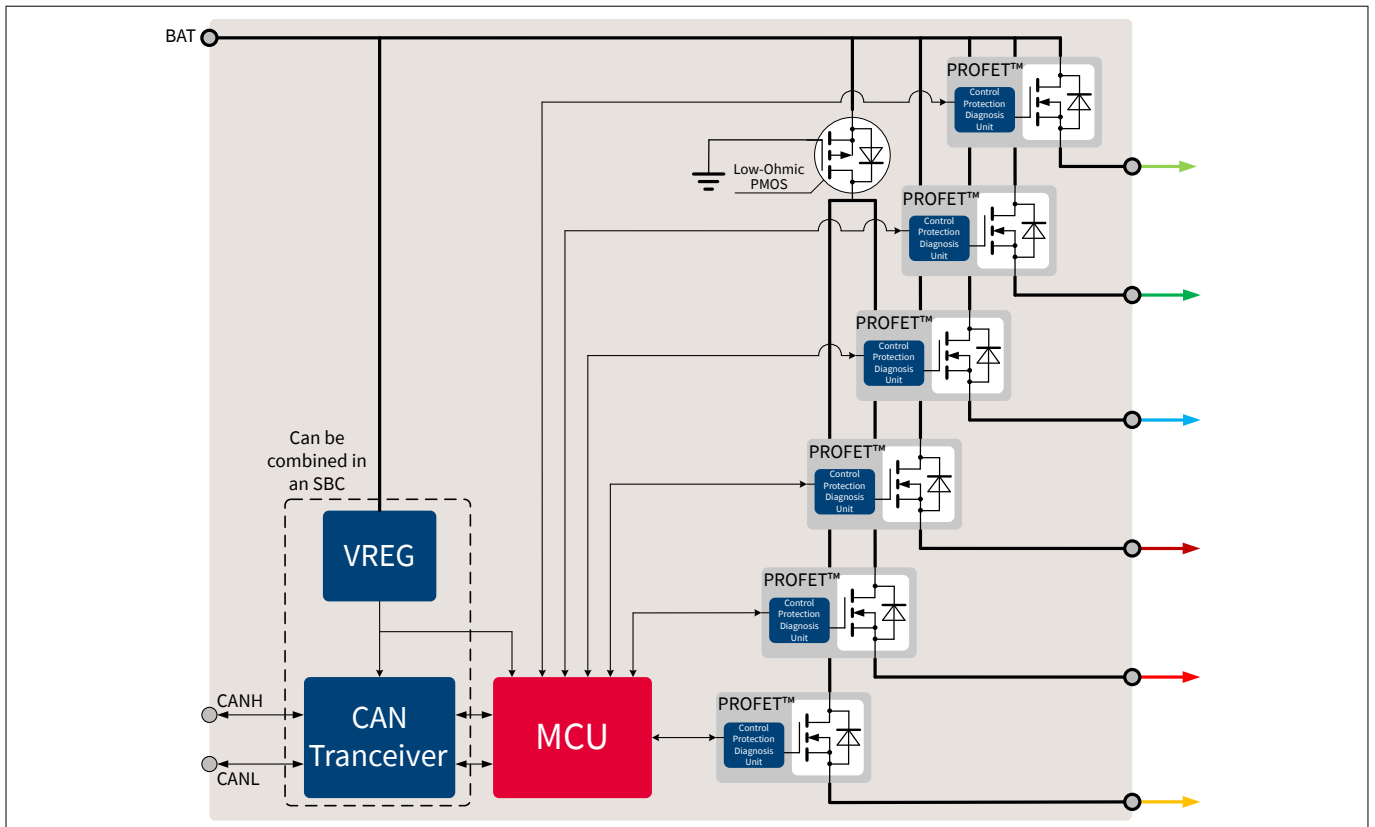


**Figure 21          Pure smart switch power distribution box**

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.

## 2 Impact on the relay box architecture

This is also an architecture which allows to spread the power distribution over multiple hubs inside the car, since there is no need anymore 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 smarts power distribution boxes, as shown on *Figure 22*.
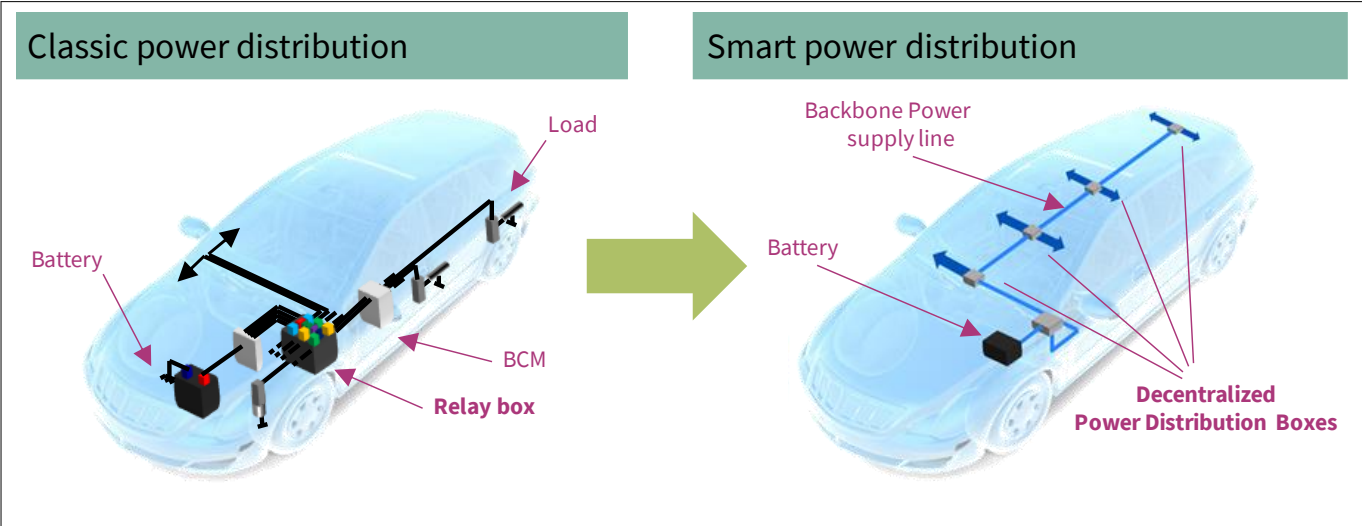


**Figure 22**          **From classic centralized power distribution to distributed power distribution**

# 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
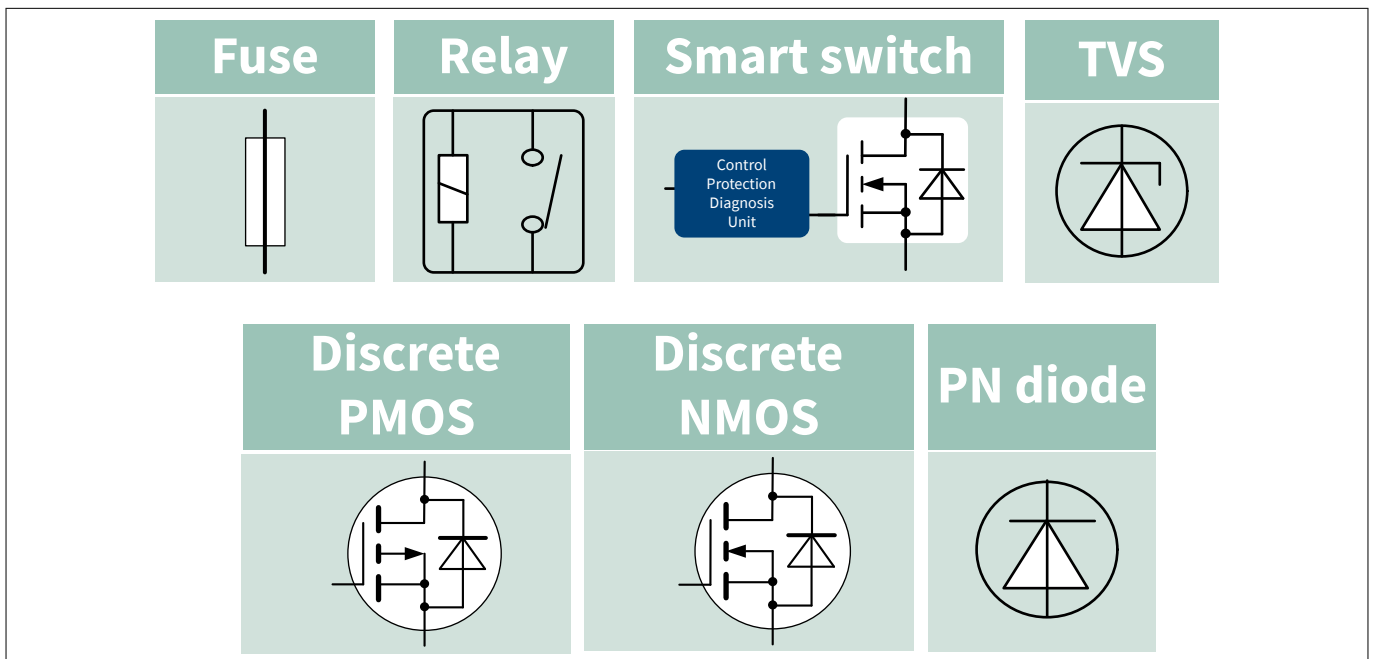- TVS: **T**ransient **V**oltage **S**uppressor

## 4.2 Symbols



**Figure 23**     **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 |
| | | |
| | | |
| | | |

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