

# Smart Power Semiconductors – Repetitive Short Circuit Operation

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## ABSTRACT

In addition to basic switching functionality, smart power switches mainly provide diagnostic and protection functions, e.g. for short circuits to the load, which makes it all the more surprising that short circuit protected smart switches have been used for years in automotive applications without there being a precise definition of a short circuit.

This article describes what Infineon has done to fill this gap. It was first necessary to define the kind of short circuits likely to occur in automotive applications and to specify the use and operating points of the smart switches. The next logical step was the standardization of the test circuit and application conditions in the AEC (Automotive Electronics Council) to allow an industry-wide comparison of the test results.

On this basis, extensive characterization testing was carried out on existing and new smart power switches, and supplementary specifications were written for repetitive short circuits, specifically in terms of the number of cycles and operating life. Furthermore, the user receives additional practical recommendations for creating a lifetime-extending software strategy in order to build electronic systems that are more robust with respect to short circuits.

## INTRODUCTION

For many years the integrated short circuit protection of smart power switches has been a function that is supposed to respond in exceptional situations, but must not be used for standard operations. Although this formulation is not particularly precise, engineers have used it for a long time and were able to build reliable and robust vehicle systems. But there have also been several negative experiences with serious consequences, which the industry refers to as “catastrophic failures” or “thermal events”. The cause was often a smart power switch that was left on its own during a permanent short circuit without any diagnostic evaluation until the cyclical thermal stress finally caused it to reach the end of its useful life.

Although such cases were rare and could always be traced back to a power switch being operated outside of its specification, action had to be taken. The goal was to provide the user with the necessary information about the power switch's lifespan or number of repeated short circuit cycles, thus enabling him to build a secure and robust system. This approach provides the basis not only for the delivery of zero-fault products, but rather for the construction of zero-fault systems by the user and therefore an important part of the “Infineon Automotive Excellence Program”.

## SHORT CIRCUITS IN AUTOMOTIVE APPLICATIONS

### DEFINITION OF A SHORT CIRCUIT

Although automotive applications have required extensive short circuit protection for years, they could not be based on a general applicable definition of a short circuit. The subject was discussed in many talks with international automobile manufacturers and suppliers and attempts were made to create a generally applicable equivalent circuit diagram based on the limited information available (see Fig. 1).

Starting with the power switch, which is normally located on an ECU (electronic control unit), we must differentiate between primary and secondary impedances. The primary impedance consists of the power supply network connected to the battery. The two components  $R_{\text{Supply}}$  and  $L_{\text{Supply}}$  contain all line and contact impedances, including the battery's internal impedance, as well as all parasitical inductivities of the network. Typical values were defined as 10 mOhms for  $R_{\text{Supply}}$  and 5  $\mu\text{H}$  for  $L_{\text{Supply}}$ . The battery voltage may range from 9 V to 14 V.

On the secondary side, things aren't quite so clear, because you cannot predict where in the network a short circuit will occur. Accordingly, we must specify areas for the secondary components in which they customarily take place. One extreme condition is a short circuit directly at the ECU's output. In this case, the consequences are approximately determined only by the impedance of the circuits on the ECU with  $R_{\text{ECU}} = 20$  mOhms.

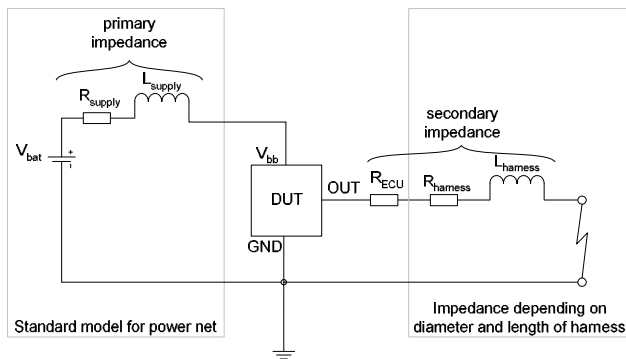


Figure 1: Equivalent short circuit with a smart high-side power switch (DUT) in automotive applications

Depending on the location of the short circuit, the secondary network is assumed to contribute 16 mOhm/m (short circuit amperage < 100 A) or 6 mOhm/m (short circuit amperage > 100 A) to  $R_{\text{Harness}}$  per cable length. For the secondary line inductivity  $L_{\text{Harness}}$ , a value of 1  $\mu\text{H}/\text{m}$  is taken into consideration.

#### SHORT CIRCUIT TEST CONDITIONS AND TEST RUNS

As indicated by the definition of a short circuit in the previous section, it is impossible to determine a short circuit with a single set of parameters. Instead, we have to deal with multidimensional parameters ranges. This applies to the secondary network and the battery voltage, but especially for the start temperature and the ambient temperature. But the short circuit behavior of the smart power switch itself has a significant impact on the analysis as well. A switch with short circuit cut-off and restart function must be analyzed differently than a switch with latch function that remains in the OFF position after a short circuit and must be actively switched on again.

Since characterizing all possible combinations would be far too complex, we attempted to develop worst-case conditions that are relevant for the life cycle and characterize only these. The following worst-case parameters were selected:

- In the 9 V to 14 V range, the worst-case battery voltage is usually 14 V, but for high-voltage switches it can also be 9 V.
- As worst-case start temperatures,  $-40^{\circ}\text{C}$  and  $25^{\circ}\text{C}$  were defined; this covers the temperature range between  $-40^{\circ}\text{C}$  and  $150^{\circ}\text{C}$ .
- The secondary-side cable length can vary between 0 m and 5 m; this range is covered by the three test points P1-P3. P1 represents the short circuit directly at the ECU's output with the secondary-side components  $R_{\text{HarnessP1}} = 20 \text{ mOhms}$  and  $L_{\text{HarnessP1}} < 1 \mu\text{H}$ . P2 indicates a short circuit with a maximum cable length of 5 meter and a large cable diameter in connection with short circuit currents > 100 A. For this case, the parameters were set as  $R_{\text{HarnessP2}} =$

50 mOhms and  $L_{\text{HarnessP2}} = 5 \mu\text{H}$ . P3 also represents a short circuit with a cable length of 5 meter, but with a smaller cable diameter and corresponding short circuit currents < 100 A. The defined values are  $R_{\text{HarnessP3}} = 100 \text{ mOhms}$  and  $L_{\text{HarnessP3}} = 5 \mu\text{H}$ .

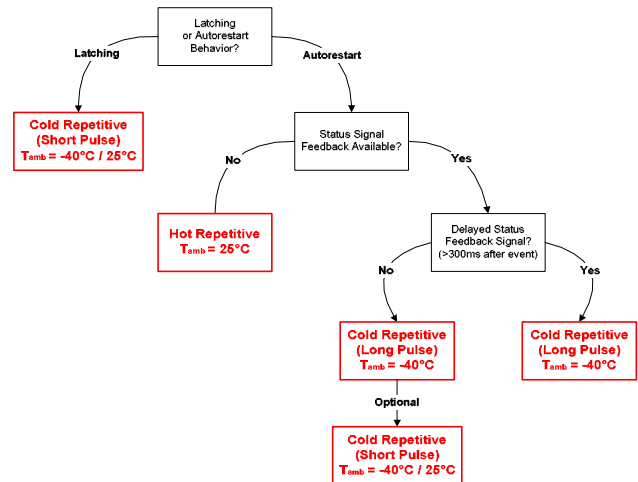


Figure 2: Decision tree for defining the relevant short circuit tests for a smart power switch

The other test conditions depend on the functional behavior of the power switch being tested and its deployment within the system application. As a rule, we differentiate between three cases, depending on whether a switch has an auto-restart or latch function, whether or not it delivers a short circuit diagnostic signal, and whether or not this diagnostic signal can be read and processed instantly or with a certain delay. The decision tree in Fig. 2 shows which test case applies to which switch type.

- *Hot repetitive short circuit:* The power switch has a restart feature and connects itself back to the short circuit's supply after a short cooling-down period. The steady-state chip temperature ranges around  $170^{\circ}\text{C}$  with little hysteresis, and a diagnosis is not present or not requested. Because of the design, the switching and thus the cycle frequency is several tens of hertz.
- *Cold repetitive short pulse short circuit:* After detecting the short circuit, the power switch either shuts off automatically (latch function) or is actively switched off 10 ms after diagnosing the short circuit. After the power switch cools down to its start temperature (which typically takes 10 seconds), the test cycle is repeated.
- *Cold repetitive long pulse short circuit:* This test is like the short pulse test, but with a longer analysis time and a switch-off delay of 300 ms after the short circuit is detected. These times were selected via a microcontroller on the basis of application-relevant analysis times.