

Introduction to Power PROFET™

About this document

Scope and purpose

This Application Note is intended to provide useful information to designers about Power PROFET™ high side power switch in the automotive environment. It provides information in addition to the Power PROFET™ datasheet, explains the motivation and rationales for specific Power PROFET™ functionalities, and focuses on special system behavior aspects and options to optimize the overall system performance and robustness.

List of the devices covered by this document: BTS50010-1TAD, BTS50015-1TAD, BTS50020-1TAD and BTS50025-1TAD.

Intended audience

This application note is targeted for all design engineers, which need to understand and possibly further improve the system performance of the Power PROFET™.

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1 Abstract

Smart, high-side power switches from Infineon® are designed to control all types of resistive, inductive, and capacitive loads. These devices provide protection and diagnostic functions and are specially designed to drive loads in harsh automotive environments.

The Power PROFET™ family is an extension of Infineon®'s smart high-side power switches portfolio to serve especially high current applications. With a $R_{DS(ON)}$ range from 1.0mOhm up to 2.5mOhm the Power PROFET™ family can serve applications with nominal currents from 20 Ampere up to 40 Ampere assuming typical automotive temperature and cooling conditions.

To serve the demanding application requirements in this high current range, Power PROFET™ design pursues the following targets:

- Easy and versatile device control
- Analogue load current diagnosis with accuracy improvement options on system level
- High energy capable power stage to drive high current loads with high inrush events or high inductivities in a repetitive manner
- Autonomous self-protection with high repetition robustness

Note: The following information is given as an implementation suggestion only, and shall not be regarded as a description or warranty of a certain functionality, condition, or quality of any device.

Note: Further generic information on high-side switches with diagnostics and protection can be found in the Application Note: [What the designer should know: Short introduction to PROFET™ +12V](#).

Note: An application note can be found on www.infineon.com which explains the different way to calibrate the current sense: [AppNote Improved SENSE Calibration and Benefits Guide1 0 Infineon.pdf](#)

2 Device control

Power PROFET™ can be easily controlled by the voltage referenced Input pin (IN pin).

2.1 Easy and Universal control

The Power PROFET™ family is primarily designed to be controlled and diagnosed from an onboard Microcontroller. This is the classic control architecture for applications like Body Control Modules (short BCM), but also for smart Electronic Control Units (short ECU) for heating applications or power distribution centers (short PDC).

Figure 1 illustrates the typical control.

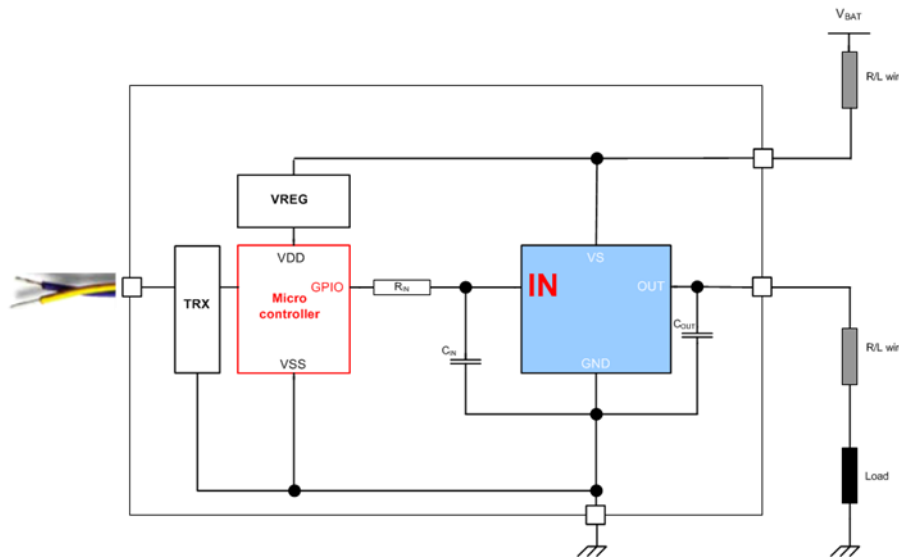


Figure 1 On Board Micro Controller Control

On board control is usually implemented by using a microcontroller supplied via a voltage regulator (VREG) and that may communicate to the peripheral world by a transceiver (TRX). Power PROFET™ is controlled by the microcontroller via a parallel general purpose Input/Output (GPIO) which is routed to the IN pin. To support such control, the LOW and HIGH level input thresholds of Power PROFET™ have been set to serve both, the use of 5V but also the use of 3.3 V rated microcontrollers.

For details regarding the input threshold please refer also to the datasheet parameters P_6.1.23 and P_6.1.24.

The Power PROFET™ family does also support off board control and diagnosis. This control architecture may be used for very small or basic load control boxes. Typical examples are solid state based plug in relays (short SSR) or other types of small SSR based relay boxes.

Figure 2 illustrates the control scheme where the controlling component is remote in a separate ECU.

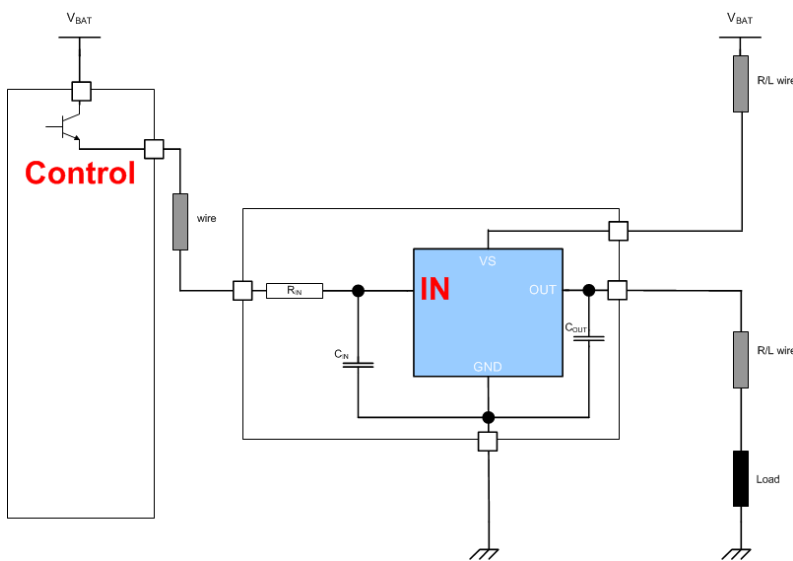


Figure 2 Off board control

To serve the control from a separate ECU and to cope with the potential risk that the control wire between the remote, controlling ECU and the Power PROFET™ may be exposed to shorts to Ground or short to Battery, Power PROFET™ offers a high voltage capable Input pin. Please refer also to the datasheet parameters P_4.1.7.

In this topology special attention may be paid to possible leakage currents and coupled disturbances of the control wire to V_{BAT} , while the controlling ECU is controlling the device to OFF mode. To ensure proper OFF condition the system leakage current of the control wire towards battery voltage ($I_{System(Leakage-To-VBAT)}$) should not exceed parameter P_6.1.26. In case this condition may be potentially violated, a sufficient termination between the IN pin and the GND pin needs to be introduced. As a rule of thumb the resistance of such termination resistor $R_{(IN-to-GND)}$ should be $R_{(IN-to-GND)} \leq \frac{MAX_V_{IN(L)}}{I_{System(Leakage-To-VBAT)}}$ with $MAX_V_{IN(L)} = 0.8V$ (see parameter 6.1.23).

With a high voltage capable Input pin Power PROFET™ supports also a system optimized control scheme, where according to Figure 2 the overall logic wiring for control can be simplified and reduced. Instead of using 2 control wires – with one wire being the wire from the remote, battery related control switch and with one wire being the Power PROFET™ and module logic GND wire - such system optimized control may use 1 control wire only. To achieve this, the IN pin of Power PROFET™ can also be connected to the V_BAT pin. Power PROFET™ control can then be achieved by switching Power PROFET™ GND wire. Since for such optimization the overall termination of the Power PROFET™ GND pin on the module is of high importance, system characterization is

recommended in case this setup is chosen. In addition special attention has to be paid, that under any circumstance the Power PROFET™ maximum rating will not be violated.

To support potential Off board diagnosis and to cope with the risk, that also the diagnosis wire may potentially be shorted to GND or to Battery, Power PROFET™ 's current sense pin (IS pin) offers also high voltage capability. Please refer also to the datasheet parameters P_4.1.10.

2.2 Battery transients robust Input Control

In the event Power PROFET™ is intended to be used in applications, where

- the Battery potential may encounter severe voltage drops, voltage outages or even intermediate battery disconnections while
- the device is and remains commanded ON (i.e. $V_{IN} \geq V_{IN(H)}$ even during such event) and
- the performance expectation is, that the ON commanded Power PROFET™ will recover in ON state once the battery voltage reaches sufficient values again

Special attention has to be paid. Datasheet chapter 5.3.3 and Figure 20 illustrates the device behavior in this special case. To ensure recovery of Power PROFET™ in ON mode once battery voltage reaches sufficient values again, the IN HIGH signal ($V_{IN} \geq V_{IN(H)}$) has to be applied after battery reaches $V_{S(EXT)}$ Min. See P_4.2.2.

To achieve this necessary voltage sequence

- a) It is recommended to use the capacitor C_{IN} . Please refer to the datasheet application information chapter, the application diagram and the Bill of Material. Please note that C_{IN} in combination R_{IN} is recommended to be compliant to ISO7637-1 and ISO7637-2 especially for ISO pulse 1 in ON mode. Please note that the dimensioning of C_{IN} depends generally on the control voltage level. The datasheet recommendation has been derived for a 5V input control voltage level. R_{IN} and C_{IN} must be sized in order that during the activation of the power supply V_{IN} must be lower than $V_{IN(H)}$ when V_S reaches $V_{S(EXT)}$ Min.
- b) Alternatively the IN signal can be re-applied once battery voltage reaches sufficient conditions again (i.e. $V_S \geq MIN_V_{S(EXT)}$, see P_4.2.2). To do so the microcontroller needs to detect such voltage transients and outages and has to react with the above stated sequence once battery voltage is recovered.

3 Power Stage

3.1 Protection Concept

Power PROFET™ embeds an autonomous self protection against excessive currents, excessive junction temperatures and excessive voltages.

3.1.1 Over current protection

To achieve highest robustness even at fault conditions like severe over currents / low ohmic short circuits, Power PROFET™ embeds an over current threshold / over current trip protection concept which latches whenever being triggered.

Whenever the load currents exceed the limit of the Current Trip Detection Level ($I_L \geq I_{CL(0)}$), see parameter P_6.1.35), the device will initiate protective switch off once the Overload Shutdown Delay Time (refer to datasheet parameter P_6.1.36) has expired. Due to this delay time a certain current overshoot may be observed depending on the di/dt load current steepness. The datasheet parameter P_6.1.35 indicates the observed over shoot for certain di/dt load current steepness. Any protective switch off will result in a latched OFF condition of the power stage. Such protective off latch can only be reset by a sufficient long OFF command from the microcontroller. To reset a protective latch the IN pin of Power PROFET™ has to be set to LOW for a duration of $t_{IN(ResetDelay)}$ (refer to datasheet parameter Delay Time to Reset Fault Signal at IS Pin after Turning OFF VIN, P_6.1.53). Thanks to the over current threshold / over current trip protection concept Power PROFET™ achieves excellent repetitive short circuit switching capability (refer to datasheet parameter P_4.1.4) with product type specific cycle rates up to 1 Million for AEC-Q100-012 test condition setup.

3.1.2 Overtemperature protection

To avoid critical junction temperatures Power PROFET™ embeds a latching overtemperature protection concept.

Whenever the junction temperature exceeds critical conditions ($T_J \geq T_{J(TRIP)}$), see P_6.1.37), the device will initiate a protective switch off. Any protective switch off will be latched. A protective off latch can only be reset by a sufficient long OFF command from the controlling microcontroller.

To reset a protective latch the IN pin of Power PROFET™ has to be set to LOW for a duration of $t_{IN(ResetDelay)}$ (refer to datasheet parameter Delay Time to Reset Fault Signal at IS Pin after Turning OFF VIN, P_6.1.53).

In order to allow overtemperature detection and reaction within time, a maximum Average Power Dissipation P_{TOT} (Parameter P_4.1.15) shall not be exceeded. Especially at operation where loads are operated in pulse width modulation (PWM) this parameter needs to be considered.

Both, the activation of an over current trip protection as well as the overtemperature protection will trigger the advanced switch off function (refer to datasheet chapter 5.1.7 - Advanced switch-off behavior). To minimize device stress during switch off, the power stage switches about ten times faster off than under normal conditions.

3.1.3 Overvoltage Protection

To achieve a well-balanced performance between key parameters like low $R_{DS(ON)}$, high transient and steady state load current capability, excellent thermal transient performance for dynamic load driver capability including high energy capability for single and repetitive clamping operation, Power PROFET™ embeds the Infineon® SMART CLAMPING concept. Infineon® SMART CLAMPING controls the power stage clamp voltage $V_{DS(CL)}$ depending on the junction temperature T_J and the

load current I_L with a positive temperature coefficient (short PTC) behavior. Hence, the higher the T_j and I_L is, the higher the clamp voltage $V_{DS(CL)}$ becomes. This functionality offers the following benefits

- Balanced power distribution across the Power PROFET™ power stage during de-energization events of inductive loads resulting in an improved E_{AS} and E_{AR} performance
- Self-controlled operation at the optimum clamping voltage
- Blocking capability for over voltage events like jump start combined with active suppression of higher rated, transient over voltages (e.g. ISO pulses 2a, 2b & 3b) across the high power rated load and power stage
- Allow to sustain load dump condition (ISO pulse 5b). When a current is flowing in the Mosfet in clamping mode, the junction temperature increase and the clamp voltage increase and will be higher that the load dump voltage.

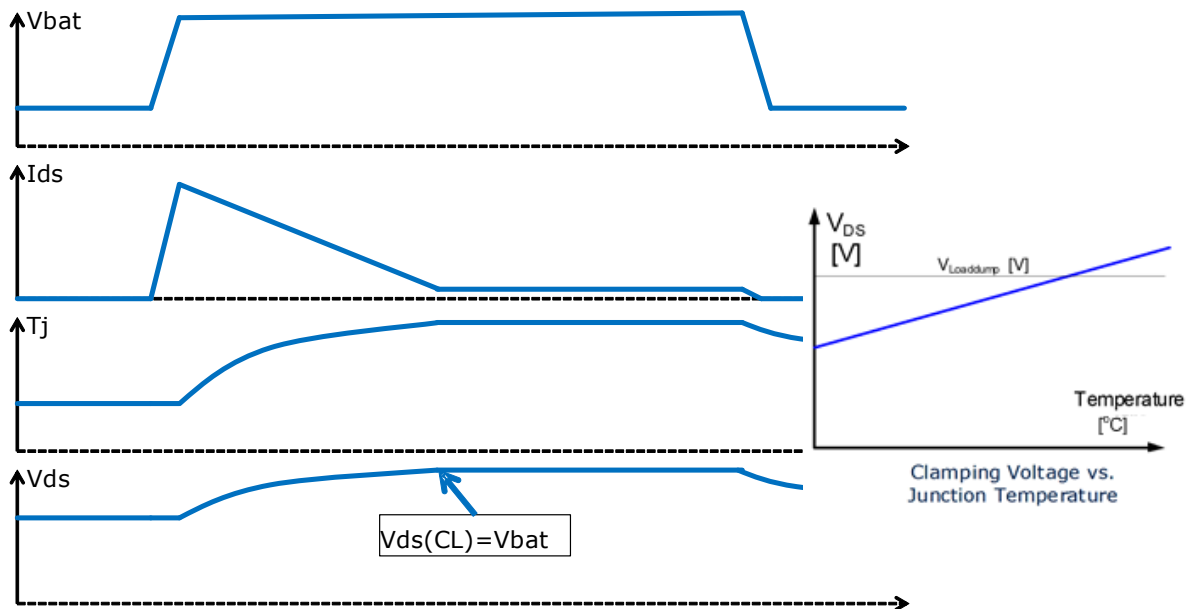


Figure 3 Overvoltage protection

3.1.4 Robustness utilization

To utilize Power PROFET™ robustness capabilities including the short circuit robustness n_{RSC1} (parameter P_4.1.4), the following recommendations should be followed:

- A Maximum Retry Cycle Rate in Fault Condition (f_{fault} , parameter P_4.1.9) should not be exceeded. In case of PWM operation it is recommended, to reduce the retry frequency during fault condition from $f_{PWM(nominal)}$ to f_{fault} . Only once the fault condition is surely overcome, the nominal PWM frequency $f_{PWM(nominal)}$ should be restored.
- The Maximum Single Pulse Current vs. Pulse Time (refer to datasheet figure 4) shall not be exceeded. Especially when Power PROFET™ is used in high current

performance / low overall $R_{TH(JA)}$ cooling condition, it is recommended to utilize the current sense function to maintain the current/pulse-time/limitations.

- To avoid unintended auto restart resulting from severe battery oscillations during short circuit switch off the later outlined RC snubber circuit may be introduced if necessary.

3.2 Low VS and Cranking capability

The Power PROFET™ concept embeds special design measures to serve the more upcoming and more demanding operation requirements at low battery voltage Power PROFET™ is able to maintain minimum dynamic undervoltage capability down 3.2V (as required in the German OEM LV124). However, ON condition at such low battery voltages cannot be maintained as requested by LV124 for duration of 19msec. Depending on the device type, ON condition can be maintained for durations of 3.6msec only. After this duration the power stage of Power PROFET™ may switch off. ON condition will resume, once battery voltage reaches sufficient conditions again ($V_S \geq \text{MIN_}V_{S(\text{EXT})}$).

3.3 Repetitive clamping

Due to special design measures in Power PROFET™ control circuit concept as well as technology composition, Power PROFET™ achieves excellent single (E_{AS}) and repetitive (E_{AR}) clamping performance. The product specific clamping performance is specified for key initial load current ($I_{L(0)}$) and initial junction temperature ($T_{J(0)}$) conditions. Please refer to datasheet parameters P_4.1.12, P_4.1.13 and P_4.1.14.

Additionally datasheet figures “Maximum Energy Dissipation for Inductive Switch OFF, EA vs. IL at $V_S = 13.5\text{ V}$ ” (Fig.5) and “Maximum Energy Dissipation Repetitive Pulse temperature derating” (Fig.6) provide all necessary data points, to derive the E_{AS} and E_{AR} performance at different conditions. In order to ensure and guarantee the maximum rating for E_{AR} , a certain number of cycles must be considered for testing and evaluation. Infineon specifies for Power PROFET™ family E_{AR} for one million of cycles. The criteria for passing the test is the device parameters must be within the electrical specification.

Exceeding the maximum ratings for E_{AS} or E_{AR} will result in a too high junction temperature, leading either directly to an immediate destruction of the device or to a degradation with a drift of the electrical parameters and reduced lifetime.

3.4 Driving Active loads

When switching motors or ECUs which have the ability to generate voltage on the OUT pin, special attention is required to limit the maximum dV_{DS}/dt . Also the device may not be able to turn on at low V_S and low V_{DS} condition. See chapter 5.1.4 in the datasheet

4 Robust Design

4.1 Loss of ECU Battery Connection, Loss of ECU Load Connection

In the event that the ECU design has to cope with the special conditions like

- Intermittent or permanent loss of battery connection while Power PROFET™ may be in ON condition driving a high current load
- Intermittent or permanent loss of load connection while Power PROFET™ may be in ON condition driving a high current load

Special design measures are recommended to avoid critical voltage conditions on all Power PROFET™ pins. The necessary design measures have to ensure, that the Power PROFET™ maximum ratings will not be violated (please refer to datasheet Maximum Rating Chapter 4.1 and Table 2).

4.1.1 Loss of Battery

Figure 4 illustrate this condition.

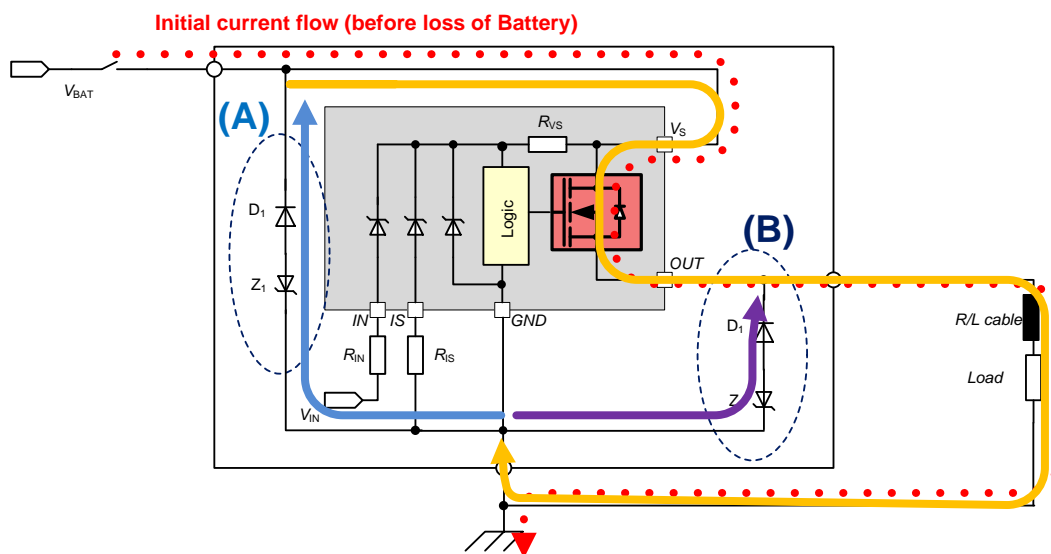


Figure 4 Loss of Battery

Before loss of ECU Battery a load current may flow from the battery through the ECU according Figure 4 red dashed line (i.e. from battery, through battery supply wire, through ECU battery connector, on the ECU PCB traces through the Power PROFET™ power stage, through ECU load connector, through load, through ground/chassis back to battery gnd pole).

In the event of Loss of Battery with high current charged supply wires and possibly, additionally driven inductive loads the voltage potential of the ECU Battery connector as well as the potential of the Power PROFET™ VS and OUT pin will drop below ground potential, once the battery starts to get disconnected. In such event a sufficient freewheeling path for the load current has to be

provided, which suppresses too critical negative voltages at Power PROFET™ VS pin until the load current flow stops. Possible options for a sufficient freewheeling can be

- A GND related clamping of the VS pin (see Figure 4 light blue freewheeling path option (A))
- A GND related clamping of the OUT pin (see Figure 4 lila freewheeling path option (B))
- Possible other GND to VS related clamping or limiting circuits (e.g. capacitor between VS and GND, other active components which provide a freewheeling and clamping circuit to GND etc.)

All peripheral protection circuits need to be dimensioned in a manner that Power PROFET™ Absolute Maximum Ratings are not violated especially P_4.1.2 and P_4.1.21.

4.1.2 Loss of Load

Figure 5 illustrate this condition.

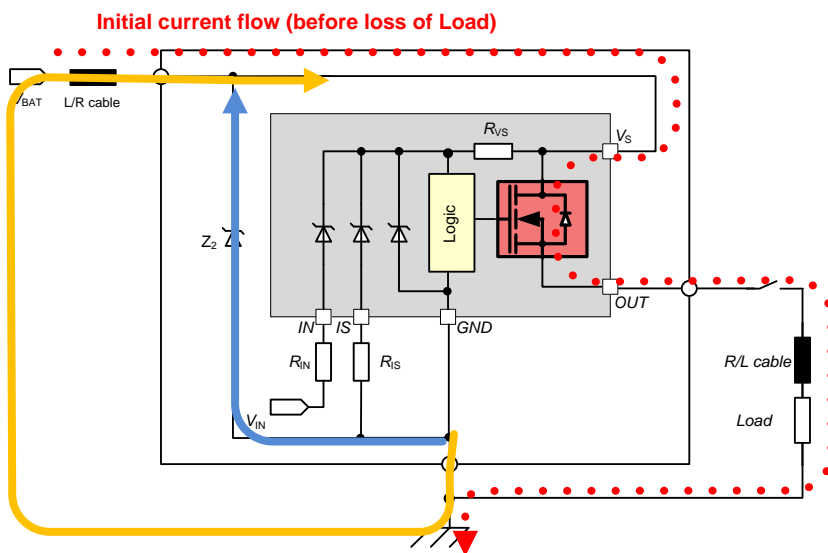


Figure 5 Loss of Load

Before loss of ECU Load a load current may flow from the battery through the ECU according Figure 5 red dashed line (i.e. from battery, through battery supply wire, through ECU battery connector, on

the ECU PCB traces through the Power PROFET™ power stage, through ECU load connector, through load, through ground/chassis back to battery gnd pole).

In the event of Loss of Load with high current charged supply wires the voltage potential of the ECU Load connector as well as the potential of the Power PROFET™ OUT and VS pin will raise above battery potential, once the load starts to get disconnected.

Figure 6 illustrates voltage transients that have been observed with a BTS50010-1TAD driving a 0.50hm load at $V_{BAT}=13.5V$ with a primary supply impedance of 5uH and 10mOhm.



Figure 6 Loss of Load – BTS50010-1TAD scope plot example

As it can be seen, an initial load current of about 25Ampere (CH7, blue curve) will result on both, the VS line (CH1, yellow curve) and the OUT line (CH3, lila curve) to peak voltages of 25Volts already.

In such event a sufficient free wheeling path or buffering circuit for the load current in the supply wire inductance has to be provided, which suppresses too critical high voltages at Power PROFET™ VS and OUT pin. Possible options for a sufficient free wheeling can be

- A GND related clamping of the VS pin (see 4 light blue free wheeling path)
- Possible other VS to GND related clamping, limiting or buffering circuits (e.g. capacitor between VS and GND, other active components which provide a feewheeling and clamping circuit to GND etc.)

All peripheral protection circuits need to be dimensioned in a manner, that Power PROFET™ Absolute Maximum Ratings are not violated including P_{6.1.33}.

4.2 Damping Oscillations on the battery line

At certain application conditions it may be observed, that Power PROFET™ shows a limited restart behavior after initially switching off severe short circuit conditions, although Power PROFET™ is designed to switch off any fault condition with an off latching output stage.

Such restart behavior may be observed under the following conditions:

- Power PROFET™ is exposed to a severe short circuit
- Power PROFET™ detects the short circuit fault condition with the over current trip protection mechanism being triggered and initiates a fast protective switch off (advanced switch off)
- Due to the high current amplitudes and high current slopes in the overall system, Power PROFET™ may cause high voltage oscillations on the VS pin, stimulating an LC circuit where L is the remaining, parasitic wire inductance and C is the remaining, overall capacitive loading of the VS pin in respect to ECU GND, and where severe voltage ringing may occur after Power PROFET™ has switched off the faulty condition

Figure 7 illustrate the system environment and highlights main contributors

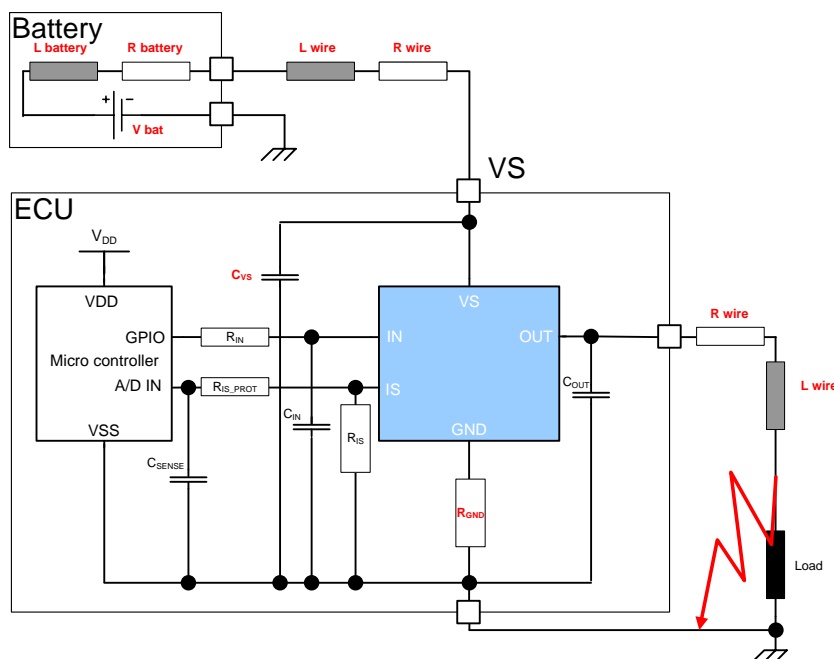


Figure 7 major system contributors to possible VS oscillation

The effect which may cause Power PROFET™ to “restart” after switching off a severe short condition follows the following “chain of effects”

- When switching off severe short circuit condition with high peak currents in the system as fastly as possible, the LC circuit between ECU VS pin and ECU GND pin is stimulated
- The oscillation depends on the overall involved inductance (e.g. $L_{prim}=L_{wire}+L_{battery}+...$), the overall involved capacity (e.g. $C_{VS-To-GND}=C_{VS}+...$) and is damped by the overall involved resistance (e.g. $R = R_{wire}+R_{battery}+...$)
- Whenever a severe oscillation causes the voltage across Power PROFET™ pins VS and GND to drop below a critical threshold in combination with critical durations ,

the protective latch off condition of Power PROFET™ may be reset due to the internal, intermediate missing supply condition of the volatile latch

Based on intense investigations including characterization and simulation the following can be concluded

- Critical system condition combinations, which may result in severe VS oscillations causing Power PROFET™ to show a limited restart behavior, do not follow clear and hard boundary conditions
- Among the parameters, which have a influence on a critical VS oscillation conditions are
 - the voltage of the system supplying battery (V_{BAT})
 - the voltage level which is applied at Power PROFET™ IN pin (V_{IN})
 - the overall primary system supply resistance including battery and wire resistance (R_{PRIM})
 - the overall primary system supply inductance including battery and wire inductance (L_{PRIM})
 - the overall secondary system supply resistance including wire and short resistance (R_{SEC})
 - the overall secondary system supply inductance including wire inductance (L_{SEC})
 - the overall resistance of the Power PROFET™ ground connection (R_{GND})

Figure 8 and Figure 9 show a “high level” summary about critical combinations that may or may not cause an oscillation severe enough to reset Power PROFET™ protective Latch being reset and Power PROFET™ to restart.

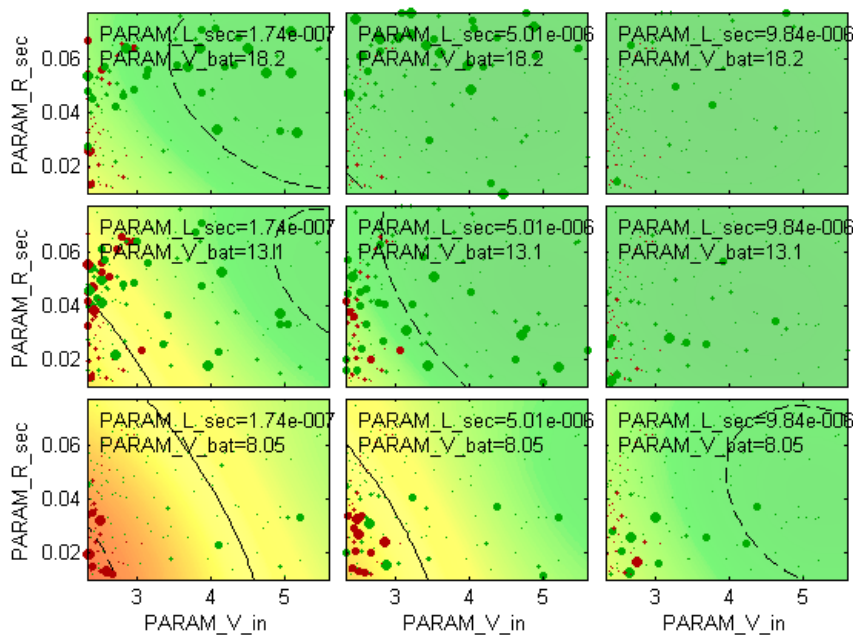


Figure 8 R_sec, L_sec, V_bat and V_in contribution to possible VS oscillation

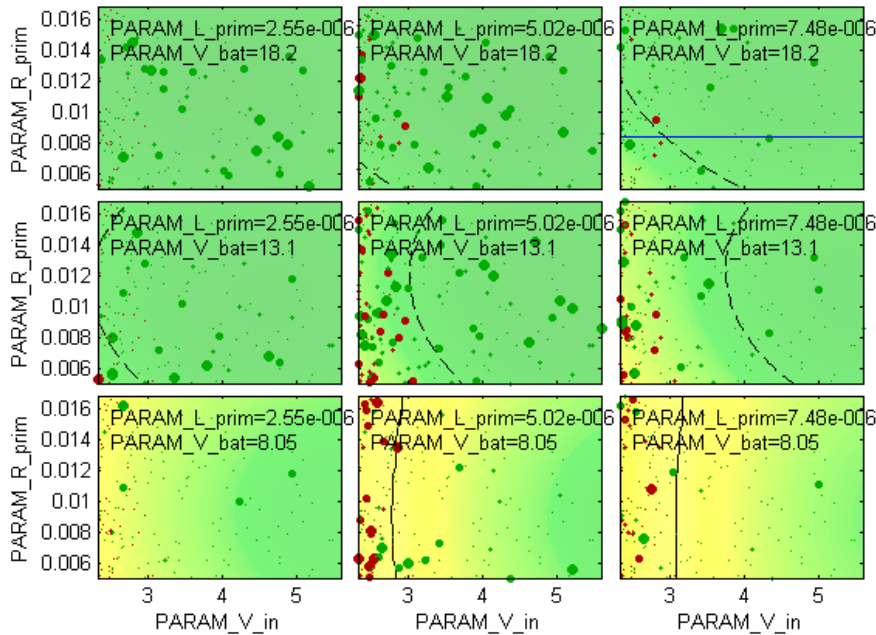


Figure 9 R_{prim}, L_{prim}, V_{bat} and V_{in} contribution to possible VS oscillation

Note: Figure 8 and Figure 9 is a “4 dimensional diagram”. Both figures consist of 3x3 2 dimensional diagrams, where per diagram 2 parameters are varies and 2 parameters remain fixed. Moving horizontally or vertically to the next 2 dimensional diagram varies on X-Axis and Y-Axis again the same parameters, but form the formerly fixed 2 other parameters on is changed.

Note: The background color of each 2 dimensional diagram gives a “statistical indication” about the probability in this combination “space”. Green indicates, that in this combinational area no or only a few restarts have been observed. Changing the color from green to yellow or even red means that the probability of restarts will in crease in this area.

Each “RED” point shows a simulated combination, where at least one restart may be observed.
 Each “GREEN” point shows a simulated combination, where the device will reliably stay latched off.

Although the background color gives a “statistical indication” about the probability in this combination “space”, it needs to be highlighted, that there are “RED” restarting conditions in green areas and “GREEN” latching conditions in yellow and red areas. Hence there is not clearly to be defined border where restarts will not happen for sure or where restarts will happen for sure and need to be suppressed by a damping snubber circuit.

Therefore it is highly recommended to introduce a damping circuit / snubber circuit, which avoids oscillations with critical low voltage and sufficient duration conditions.

Infineon recommends here the following options

4.2.1 RS snubber circuit - option A

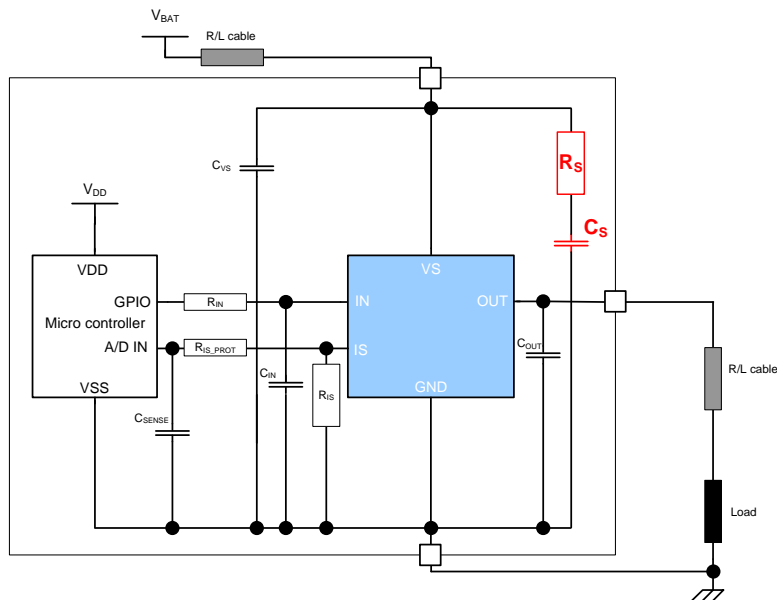


Figure 10 Option A - RC snubber network per VS battery feed

To effectively damp possible VS oscillations it is recommended, to introduce per module battery feed a snubber circuit which is connected between VS and GND. For dimensioning recommendations please refer to datasheet “Application Information” chapter and “Bill of material” table.

Introducing such snubber offers the benefits:

- RC snubber needs to be placed only once per battery feed
- RC snubber offers supporting damping and clamping effects on the peripheral circuitry which is supplied by this VS rail (including externally applied, transient over voltages)
- No deterioration of other system performance including EMC

4.2.2 RS snubber circuit - option B

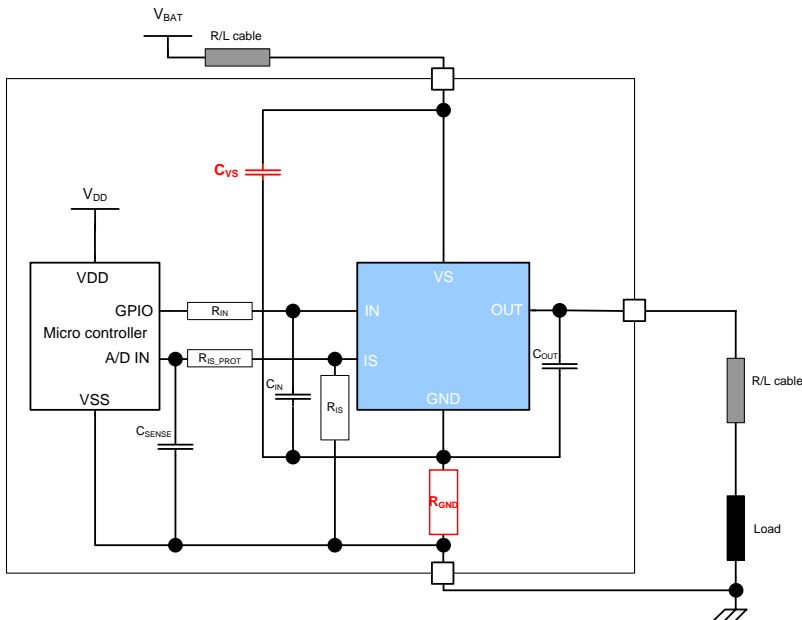


Figure 11 Option B - RC snubber network per IC

Alternatively possible VS oscillations can also be damped with the proposed option B circuit. For dimensioning recommendations please refer to datasheet “Application Information” chapter and “Bill of material” table.

Introducing such snubber offers the benefits:

- Due to the dimensioning of C_{VS} and R_{GND} this RC snubber offers a lower system cost impact compared to option A

However, this circuit has also the following effects

- Mainly beneficial for applications where only one or just a few Power PROFET™ are used
- Although R_{GND} needs to be rated single digit OHM, R_{GND} in the Power PROFET™ GND path will generate an additional, minor GND shift. C_{VS} and R_{GND} may deteriorate the overall EMC (DPI) performance.

Since Figure 8 and Figure 9 show, that there are multiple combinations, where a too severe VS oscillation and the risk of an unintended restart / reset of the protective latch is minor or not even present, specific investigations under the targeted, application specific conditions may be run, in case none of the proposed RC snubbers shall be introduced.

4.3 EMC optimized design

Infineon offers as a special service a product specific EMC report, which outlines the device EMC performance in terms of generated emission, DPI susceptibility and ISO pulse robustness. To achieve best EMC system performance and ISO pulse robustness it is recommended, to follow the dimensioning and layout recommendations of this EMC report.

5 Conclusion

With PowerPROFET™ Infineon continues its path to introduce smart semiconductors in even higher current rated automotive applications. With PowerPROFET™ customers can benefit from multiple system advantages using a solid state based high side switches instead of electromechanical switches. The benefits are versatile.

- Noise-less switching of high current loads
- Possibility to control the output power to nominal needs by means of PWM
- Possibility to diagnose the load
- Possibility to optimize overall system e.g. by optimized and downsizing the load wire (utilizing current sense in combination with wire protection software routine in controlling micro controller), simplification and overall reduction of wiring (via new, non serviceable mounting space enabling)

Revision History

V2.0, 2019-02-06 (Major changes since the last revision)

Page or Reference	Description of change
Page 4 and 5	Correct name PowerPROFET™

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