

## Smart High-Side Power Switch



### Features

- Overload protection
- Current limitation
- Short circuit protection
- Thermal shutdown
- Overvoltage protection (including load dump)
- Fast demagnetization of inductive loads
- Reverse battery protection<sup>1)</sup>
- Undervoltage and overvoltage shutdown with auto-restart and hysteresis
- Open drain diagnostic output
- Open load detection in ON-state
- CMOS compatible input
- Loss of ground and loss of  $V_{bb}$  protection
- **Electrostatic discharge (ESD)** protection
- Green Product (RoHS compliant)
- AEC Qualified

### Product Summary

|                        |              |            |    |
|------------------------|--------------|------------|----|
| Overvoltage protection | $V_{bb(AZ)}$ | 43         | V  |
| Operating voltage      | $V_{bb(on)}$ | 5.0 ... 34 | V  |
| On-state resistance    | $R_{ON}$     | 200        | mΩ |
| Load current (ISO)     | $I_{L(ISO)}$ | 2.3        | A  |
| Current limitation     | $I_{L(SCr)}$ | 4          | A  |

PG-TO263-5-2

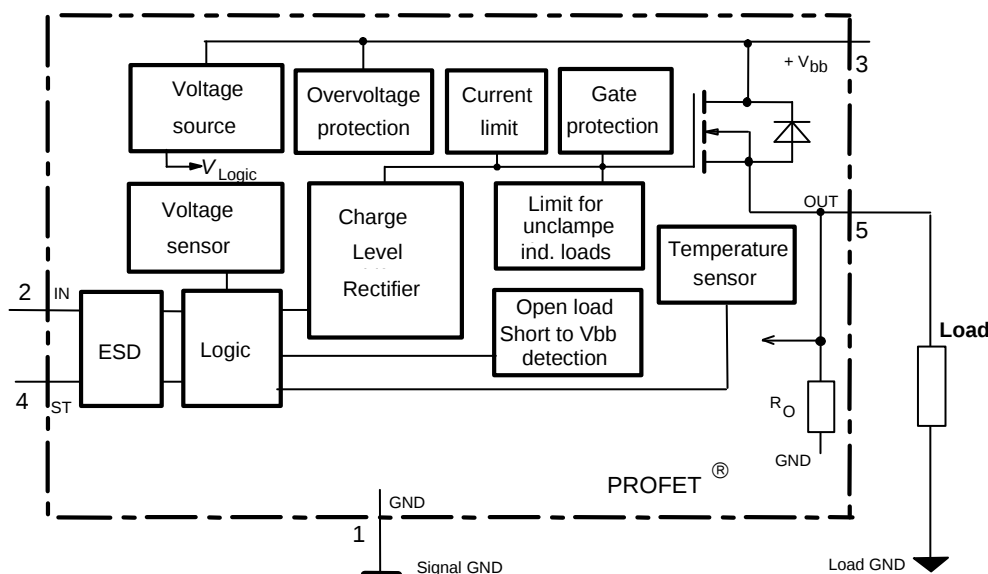


### Application

- $\mu$ C compatible power switch with diagnostic feedback for 12 V and 24 V DC grounded loads
- All types of resistive, inductive and capacitive loads
- Replaces electromechanical relays, fuses and discrete circuits

### General Description

N channel vertical power FET with charge pump, ground referenced CMOS compatible input and diagnostic feedback, monolithically integrated in Smart SIPMOS® technology. Fully protected by embedded protection functions.



<sup>1)</sup> With external current limit (e.g. resistor  $R_{GND}=150\ \Omega$ ) in GND connection, resistor in series with ST connection, reverse load current limited by connected load.

| Pin | Symbol           |   | Function                                                         |
|-----|------------------|---|------------------------------------------------------------------|
| 1   | GND              | - | Logic ground                                                     |
| 2   | IN               | I | Input, activates the power switch in case of logical high signal |
| 3   | Vbb              | + | Positive power supply voltage,<br>the tab is shorted to this pin |
| 4   | ST               | S | Diagnostic feedback, low on failure                              |
| 5   | OUT<br>(Load, L) | O | Output to the load                                               |

**Maximum Ratings** at  $T_j = 25\text{ °C}$  unless otherwise specified

| Parameter                                                                                                                                                                                                                       | Symbol                    | Values       | Unit |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|--------------|------|
| Supply voltage (overvoltage protection see page 4)                                                                                                                                                                              | $V_{bb}$                  | 43           | V    |
| Supply voltage for short circuit protection<br>$T_{j\text{ start}} = -40 \dots +150\text{ °C}$                                                                                                                                  | $V_{bb}$                  | 34           | V    |
| Load dump protection <sup>2)</sup> $V_{\text{LoadDump}} = U_A + V_s$ , $U_A = 13.5\text{ V}$<br>$R_1^3 = 2\text{ }\Omega$ , $R_L = 5.3\text{ }\Omega$ , $t_d = 200\text{ ms}$ , IN= low or high                                 | $V_{\text{Load dump}}^4)$ | 60           | V    |
| Load current (Short circuit current, see page 5)                                                                                                                                                                                | $I_L$                     | self-limited | A    |
| Operating temperature range                                                                                                                                                                                                     | $T_j$                     | -40 ... +150 | °C   |
| Storage temperature range                                                                                                                                                                                                       | $T_{\text{stg}}$          | -55 ... +150 |      |
| Power dissipation (DC), $T_C \leq 25\text{ °C}$                                                                                                                                                                                 | $P_{\text{tot}}$          | 18           | W    |
| Inductive load switch-off energy dissipation, single pulse<br>$V_{bb} = 12\text{ V}$ , $T_{j,\text{start}} = 150\text{ °C}$ , $T_C = 150\text{ °C}$ const.<br>$I_L = 2.3\text{ A}$ , $Z_L = 98\text{ mH}$ , $0\text{ }\Omega$ : | $E_{AS}$                  | 335          | mJ   |
| Electrostatic discharge capability (ESD) IN:<br>(Human Body Model) all other pins:<br>acc. MIL-STD883D, method 3015.7 and ESD assn. std. S5.1-1993                                                                              | $V_{\text{ESD}}$          | 1.0<br>2.0   | kV   |
| Input voltage (DC)                                                                                                                                                                                                              | $V_{\text{IN}}$           | -10 ... +16  | V    |
| Current through input pin (DC)                                                                                                                                                                                                  | $I_{\text{IN}}$           | $\pm 2.0$    | mA   |
| Current through status pin (DC)                                                                                                                                                                                                 | $I_{\text{ST}}$           | $\pm 5.0$    |      |
| see internal circuit diagrams page 7                                                                                                                                                                                            |                           |              |      |

## Thermal Characteristics

| Parameter and Conditions                   | Symbol            | Values |     |     | Unit |
|--------------------------------------------|-------------------|--------|-----|-----|------|
|                                            |                   | min    | typ | max |      |
| Thermal resistance chip - case:            | $R_{\text{thJC}}$ | --     | --  | 7   | K/W  |
| junction - ambient (free air):             | $R_{\text{thJA}}$ | --     | --  | 75  |      |
| SMD version, device on PCB <sup>5)</sup> : |                   |        | 39  |     |      |

<sup>2)</sup> Supply voltages higher than  $V_{bb(AZ)}$  require an external current limit for the GND and status pins, e.g. with a  $150\text{ }\Omega$  resistor in the GND connection and a  $15\text{ k}\Omega$  resistor in series with the status pin. A resistor for the protection of the input is integrated.

<sup>3)</sup>  $R_1$  = internal resistance of the load dump test pulse generator

<sup>4)</sup>  $V_{\text{Load dump}}$  is setup without the DUT connected to the generator per ISO 7637-1 and DIN 40839

<sup>5)</sup> Device on  $50\text{ mm} \times 50\text{ mm} \times 1.5\text{ mm}$  epoxy PCB FR4 with  $6\text{ cm}^2$  (one layer,  $70\text{ }\mu\text{m}$  thick) copper area for  $V_{bb}$  connection. PCB is vertical without blown air.

## Electrical Characteristics

| Parameter and Conditions<br>at $T_j = 25^\circ\text{C}$ , $V_{bb} = 12\text{ V}$ unless otherwise specified | Symbol | Values |     |     | Unit |
|-------------------------------------------------------------------------------------------------------------|--------|--------|-----|-----|------|
|                                                                                                             |        | min    | typ | max |      |

### Load Switching Capabilities and Characteristics

|                                                                                                                                  |                  |     |            |            |                        |
|----------------------------------------------------------------------------------------------------------------------------------|------------------|-----|------------|------------|------------------------|
| On-state resistance (pin 3 to 5)<br>$I_L = 1.8\text{ A}$<br>$T_j = 25^\circ\text{C}$ :<br>$T_j = 150^\circ\text{C}$ :            | $R_{ON}$         | --  | 160<br>320 | 200<br>400 | $\text{m}\Omega$       |
| Nominal load current, ISO Norm (pin 3 to 5)<br>$V_{ON} = 0.5\text{ V}$ , $T_C = 85^\circ\text{C}$                                | $I_{L(ISO)}$     | 1.8 | 2.3        | --         | A                      |
| Output current (pin 5) while GND disconnected or<br>GND pulled up, $V_{bb} = 30\text{ V}$ , $V_{IN} = 0$ , see diagram<br>page 8 | $I_{L(GNDhigh)}$ | --  | --         | 10         | mA                     |
| Turn-on time<br>IN $\square$ to 90% $V_{OUT}$ :                                                                                  | $t_{on}$         | 80  | 200        | 400        | $\mu\text{s}$          |
| Turn-off time<br>IN $\sqcap$ to 10% $V_{OUT}$ :                                                                                  | $t_{off}$        | 80  | 200        | 400        | $\mu\text{s}$          |
| Slew rate on<br>10 to 30% $V_{OUT}$ , $R_L = 12\ \Omega$ , $T_j = -40\dots+150^\circ\text{C}$                                    | $dV/dt_{on}$     | 0.1 | --         | 1          | $\text{V}/\mu\text{s}$ |
| Slew rate off<br>70 to 40% $V_{OUT}$ , $R_L = 12\ \Omega$ , $T_j = -40\dots+150^\circ\text{C}$                                   | $-dV/dt_{off}$   | 0.1 | --         | 1          | $\text{V}/\mu\text{s}$ |

### Operating Parameters

|                                                                                                               |                        |     |          |            |               |
|---------------------------------------------------------------------------------------------------------------|------------------------|-----|----------|------------|---------------|
| Operating voltage <sup>6)</sup><br>$T_j = -40\dots+150^\circ\text{C}$ :                                       | $V_{bb(on)}$           | 5.0 | --       | 34         | V             |
| Undervoltage shutdown<br>$T_j = -40\dots+150^\circ\text{C}$ :                                                 | $V_{bb(under)}$        | 3.5 | --       | 5.0        | V             |
| Undervoltage restart<br>$T_j = -40\dots+25^\circ\text{C}$ :<br>$T_j = +150^\circ\text{C}$ :                   | $V_{bb(u\ rst)}$       | --  | --       | 5.0<br>7.0 | V             |
| Undervoltage restart of charge pump<br>see diagram page 12<br>$T_j = -40\dots+150^\circ\text{C}$ :            | $V_{bb(ucp)}$          | --  | 5.6      | 7.0        | V             |
| Undervoltage hysteresis<br>$\Delta V_{bb(under)} = V_{bb(u\ rst)} - V_{bb(under)}$                            | $\Delta V_{bb(under)}$ | --  | 0.2      | --         | V             |
| Overvoltage shutdown<br>$T_j = -40\dots+150^\circ\text{C}$ :                                                  | $V_{bb(over)}$         | 34  | --       | 43         | V             |
| Overvoltage restart<br>$T_j = -40\dots+150^\circ\text{C}$ :                                                   | $V_{bb(o\ rst)}$       | 33  | --       | --         | V             |
| Overvoltage hysteresis<br>$T_j = -40\dots+150^\circ\text{C}$ :                                                | $\Delta V_{bb(over)}$  | --  | 0.5      | --         | V             |
| Overvoltage protection <sup>7)</sup><br>$I_{bb} = 40\text{ mA}$<br>$T_j = -40\dots+150^\circ\text{C}$ :       | $V_{bb(AZ)}$           | 42  | 47       | --         | V             |
| Standby current (pin 3)<br>$V_{IN} = 0$<br>$T_j = -40\dots+25^\circ\text{C}$ :<br>$T_j = 150^\circ\text{C}$ : | $I_{bb(off)}$          | --  | 10<br>12 | 23<br>28   | $\mu\text{A}$ |

<sup>6)</sup> At supply voltage increase up to  $V_{bb} = 5.6\text{ V}$  typ without charge pump,  $V_{OUT} \approx V_{bb} - 2\text{ V}$

<sup>7)</sup> See also  $V_{ON(CL)}$  in table of protection functions and circuit diagram page 8.

| Parameter and Conditions<br>at $T_j = 25^\circ\text{C}$ , $V_{bb} = 12\text{ V}$ unless otherwise specified | Symbol              | Values |     |     | Unit          |
|-------------------------------------------------------------------------------------------------------------|---------------------|--------|-----|-----|---------------|
|                                                                                                             |                     | min    | typ | max |               |
| Leakage output current (included in $I_{bb(\text{off})}$ )<br>$V_{IN}=0$                                    | $I_{L(\text{off})}$ | --     | --  | 12  | $\mu\text{A}$ |
| Operating current (Pin 1) <sup>8)</sup> , $V_{IN}=5\text{ V}$ ,<br>$T_j=-40\dots+150^\circ\text{C}$         | $I_{GND}$           | --     | 1.8 | 3.5 | mA            |

### Protection Functions<sup>9)</sup>

|                                                                                                                                              |                     |                 |                 |               |                  |
|----------------------------------------------------------------------------------------------------------------------------------------------|---------------------|-----------------|-----------------|---------------|------------------|
| Initial peak short circuit current limit (pin 3 to 5)<br>$T_j=-40^\circ\text{C}$ :<br>$T_j=25^\circ\text{C}$ :<br>$T_j=+150^\circ\text{C}$ : | $I_{L(\text{SCp})}$ | 5.5<br>4.5<br>3 | 9.5<br>7.5<br>5 | 13<br>11<br>7 | A                |
| Repetitive short circuit shutdown current limit<br>$T_j = T_{jt}$ (see timing diagrams, page 10)                                             | $I_{L(\text{SCr})}$ | --              | 4               | --            | A                |
| Output clamp (inductive load switch off)<br>at $V_{OUT} = V_{bb} - V_{ON(\text{CL})}$ $I_L = 40\text{ mA}$ :                                 | $V_{ON(\text{CL})}$ | 41              | 47              | 53            | V                |
| Thermal overload trip temperature                                                                                                            | $T_{jt}$            | 150             | --              | --            | $^\circ\text{C}$ |
| Thermal hysteresis                                                                                                                           | $\Delta T_{jt}$     | --              | 10              | --            | K                |
| Reverse battery (pin 3 to 1) <sup>10)</sup>                                                                                                  | $-V_{bb}$           | --              | --              | 32            | V                |

### Diagnostic Characteristics

|                                                                                                             |                      |          |          |            |            |
|-------------------------------------------------------------------------------------------------------------|----------------------|----------|----------|------------|------------|
| Open load detection current<br>(on-condition) $T_j=-40^\circ\text{C}$ :<br>$T_j=25\dots150^\circ\text{C}$ : | $I_L(\text{OL})$     | 10<br>10 | --<br>-- | 200<br>150 | mA         |
| Open load detection voltage <sup>11)</sup> (off-condition)<br>$T_j=-40\dots150^\circ\text{C}$ :             | $V_{OUT(\text{OL})}$ | 2        | 3        | 4          | V          |
| Internal output pull down<br>(pin 5 to 1), $V_{OUT}=5\text{ V}$ , $T_j=-40\dots150^\circ\text{C}$           | $R_O$                | 4        | 10       | 30         | k $\Omega$ |

<sup>8)</sup> Add  $I_{ST}$ , if  $I_{ST} > 0$ , add  $I_{IN}$ , if  $V_{IN} > 5.5\text{ V}$

<sup>9)</sup> Integrated protection functions are designed to prevent IC destruction under fault conditions described in the data sheet. Fault conditions are considered as "outside" normal operating range. Protection functions are not designed for continuous repetitive operation.

<sup>10)</sup> Requires  $150\ \Omega$  resistor in GND connection. The reverse load current through the intrinsic drain-source diode has to be limited by the connected load. Note that the power dissipation is higher compared to normal operating conditions due to the voltage drop across the intrinsic drain-source diode. The temperature protection is not active during reverse current operation! Input and Status currents have to be limited (see max. ratings page 2 and circuit page 8).

<sup>11)</sup> External pull up resistor required for open load detection in off state.

| Parameter and Conditions<br>at $T_j = 25\text{ }^{\circ}\text{C}$ , $V_{bb} = 12\text{ V}$ unless otherwise specified                                                                                                                                              | Symbol                          | Values          |                 |                  | Unit          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|-----------------|-----------------|------------------|---------------|
|                                                                                                                                                                                                                                                                    |                                 | min             | typ             | max              |               |
| Input and Status Feedback <sup>12)</sup>                                                                                                                                                                                                                           |                                 |                 |                 |                  |               |
| Input resistance<br>see circuit page 7                                                                                                                                                                                                                             | $R_I$                           | 2.5             | 3.5             | 6                | k $\Omega$    |
| Input turn-on threshold voltage $\nearrow$ $T_j = -40..+150^{\circ}\text{C}$ :                                                                                                                                                                                     | $V_{IN(T+)}$                    | 1.7             | --              | 3.5              | V             |
| Input turn-off threshold voltage $\searrow$ $T_j = -40..+150^{\circ}\text{C}$ :                                                                                                                                                                                    | $V_{IN(T-)}$                    | 1.5             | --              | --               | V             |
| Input threshold hysteresis                                                                                                                                                                                                                                         | $\Delta V_{IN(T)}$              | --              | 0.5             | --               | V             |
| Off state input current (pin 2), $V_{IN} = 0.4\text{ V}$ ,<br>$T_j = -40..+150^{\circ}\text{C}$                                                                                                                                                                    | $I_{IN(off)}$                   | 1               | --              | 50               | $\mu\text{A}$ |
| On state input current (pin 2), $V_{IN} = 3.5\text{ V}$ ,<br>$T_j = -40..+150^{\circ}\text{C}$                                                                                                                                                                     | $I_{IN(on)}$                    | 20              | 50              | 90               | $\mu\text{A}$ |
| Delay time for status with open load after switch<br>off<br>(see timing diagrams, page 11), $T_j = -40..+150^{\circ}\text{C}$                                                                                                                                      | $t_{d(ST\ OL4)}$                | 100             | 400             | 800              | $\mu\text{s}$ |
| Status invalid after positive input slope<br>(open load) $T_j = -40 \dots +150^{\circ}\text{C}$ :                                                                                                                                                                  | $t_{d(ST)}$                     | --              | 250             | 600              | $\mu\text{s}$ |
| Status output (open drain)<br>Zener limit voltage $T_j = -40...+150^{\circ}\text{C}$ , $I_{ST} = +1.6\text{ mA}$ :<br>ST low voltage $T_j = -40...+25^{\circ}\text{C}$ , $I_{ST} = +1.6\text{ mA}$ :<br>$T_j = +150^{\circ}\text{C}$ , $I_{ST} = +1.6\text{ mA}$ : | $V_{ST(high)}$<br>$V_{ST(low)}$ | 5.4<br>--<br>-- | 6.1<br>--<br>-- | --<br>0.4<br>0.6 | V             |

<sup>12)</sup> If a ground resistor  $R_{GND}$  is used, add the voltage drop across this resistor.

## Truth Table

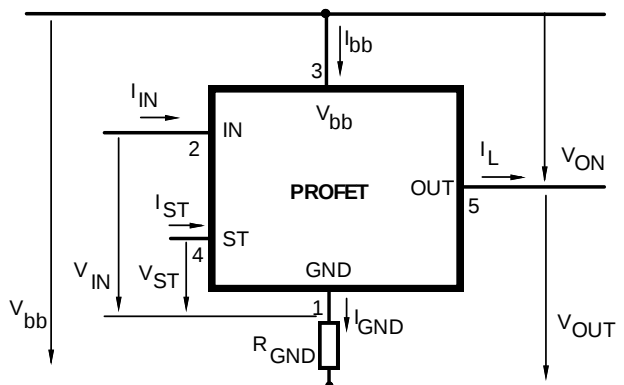
|                                  | Input-level | Output level   | Status                |
|----------------------------------|-------------|----------------|-----------------------|
| Normal operation                 | L           | L              | H                     |
|                                  | H           | H              | H                     |
| Open load                        | L           | <sup>13)</sup> | H (L <sup>14)</sup> ) |
|                                  | H           | H              | L                     |
| Short circuit to V <sub>bb</sub> | L           | H              | L <sup>15)</sup>      |
|                                  | H           | H              | H (L <sup>16)</sup> ) |
| Overtemperature                  | L           | L              | H                     |
|                                  | H           | L              | L                     |
| Under-voltage                    | L           | L              | H                     |
|                                  | H           | L              | H                     |
| Overvoltage                      | L           | L              | H                     |
|                                  | H           | L              | H                     |

L = "Low" Level  
H = "High" Level

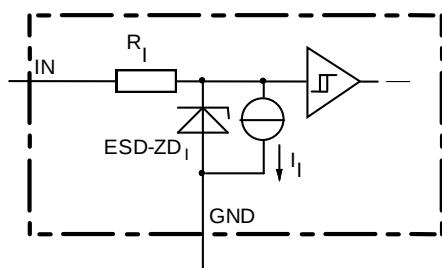
X = don't care

Z = high impedance, potential depends on external circuit  
Status signal after the time delay shown in the diagrams (see fig 5. page 11...12)

## Terms

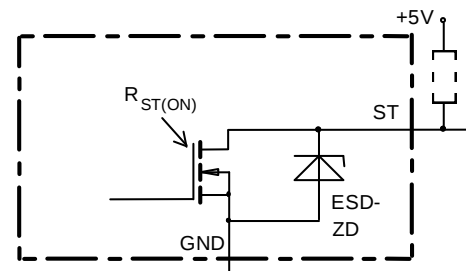


## Input circuit (ESD protection)



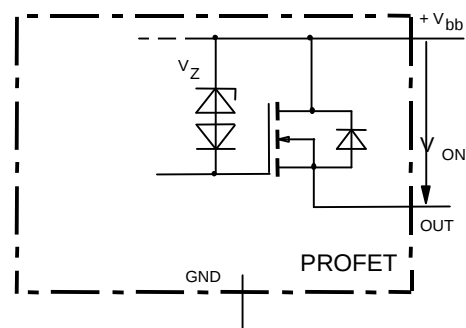
ESD zener diodes are not to be used as voltage clamp at DC conditions. Operation in this mode may result in a drift of the zener voltage (increase of up to 1 V).

## Status output



ESD-Zener diode: 6.1 V typ., max 5 mA;  
 $R_{ST(ON)} < 380 \Omega$  at 1.6 mA, ESD zener diodes are not to be used as voltage clamp at DC conditions.  
Operation in this mode may result in a drift of the zener voltage (increase of up to 1 V).

## Inductive and overvoltage output clamp



$V_{ON}$  clamped to 47 V typ.

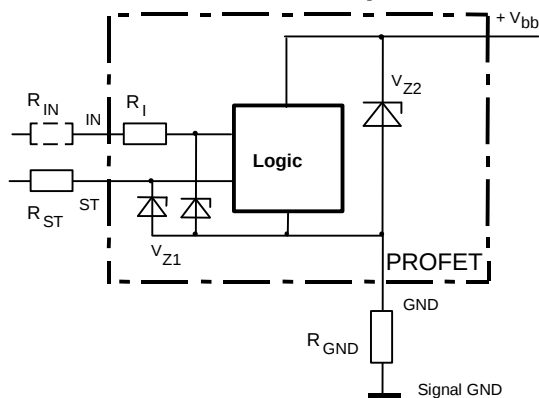
<sup>13)</sup> Power Transistor off, high impedance

<sup>14)</sup> with external resistor between pin 3 and pin 5

<sup>15)</sup> An external short of output to  $V_{bb}$ , in the off state, causes an internal current from output to ground. If  $R_{GND}$  is used, an offset voltage at the GND and ST pins will occur and the  $V_{ST \text{ low}}$  signal may be errorious.

<sup>16)</sup> Low resistance to  $V_{bb}$  may be detected in ON-state by the no-load-detection

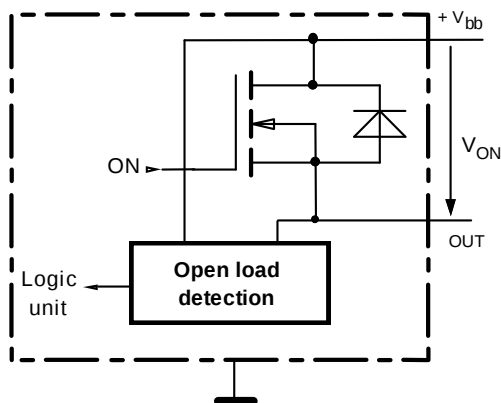
## Overvolt. and reverse batt. protection



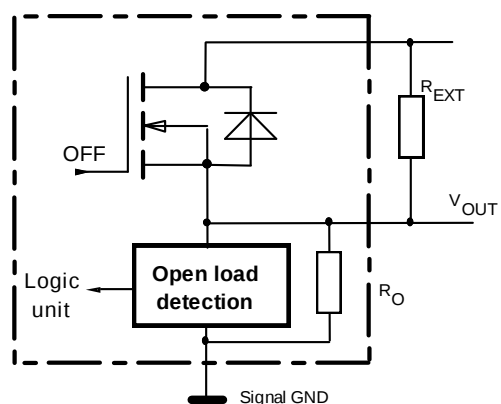
$V_{Z1} = 6.2 \text{ V typ.}$ ,  $V_{Z2} = 47 \text{ V typ.}$ ,  $R_{GND} = 150 \Omega$ ,  $R_{ST} = 15 \text{ k}\Omega$ ,  $R_I = 3.5 \text{ k}\Omega \text{ typ.}$

## Open-load detection

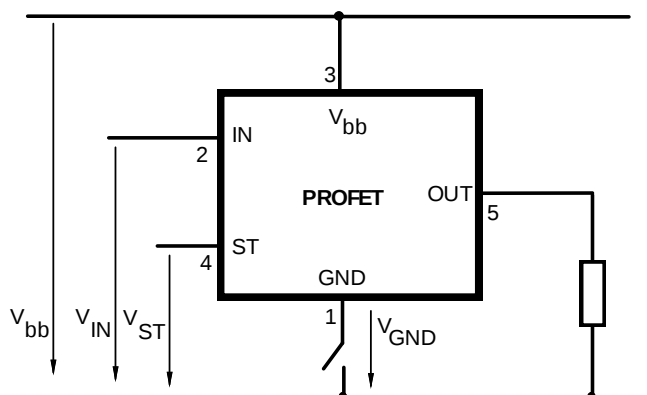
ON-state diagnostic condition:  $V_{ON} < R_{ON} * I_{L(OL)}$ ; IN high



OFF-state diagnostic condition:  $V_{OUT} > 3 \text{ V typ.}$ ; IN low

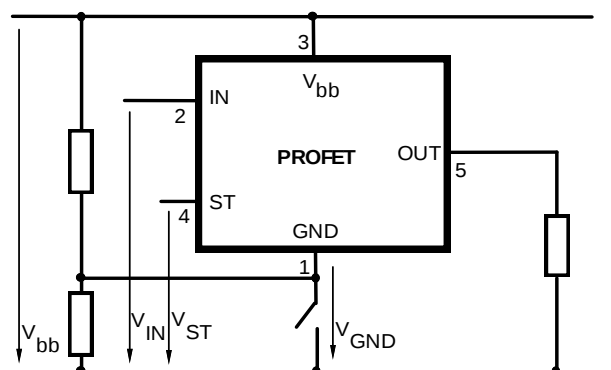


## GND disconnect



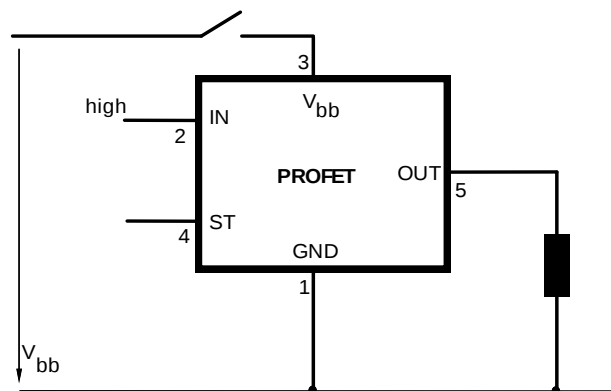
Any kind of load. In case of Input=high is  $V_{OUT} \approx V_{IN} - V_{IN(T+)}$ .  
Due to  $V_{GND} > 0$ , no  $V_{ST} = \text{low signal}$  available.

## GND disconnect with GND pull up



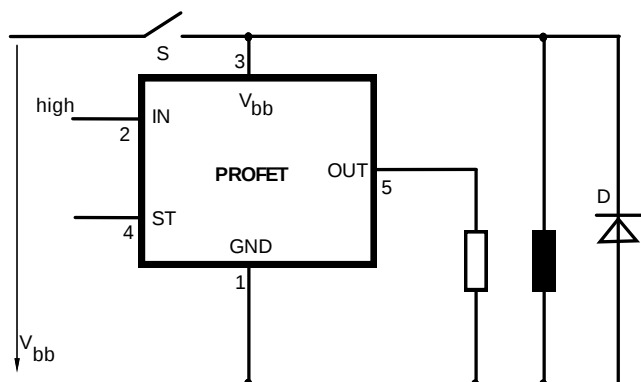
Any kind of load. If  $V_{GND} > V_{IN} - V_{IN(T+)}$  device stays off  
Due to  $V_{GND} > 0$ , no  $V_{ST} = \text{low signal}$  available.

## V<sub>bb</sub> disconnect with energized inductive load



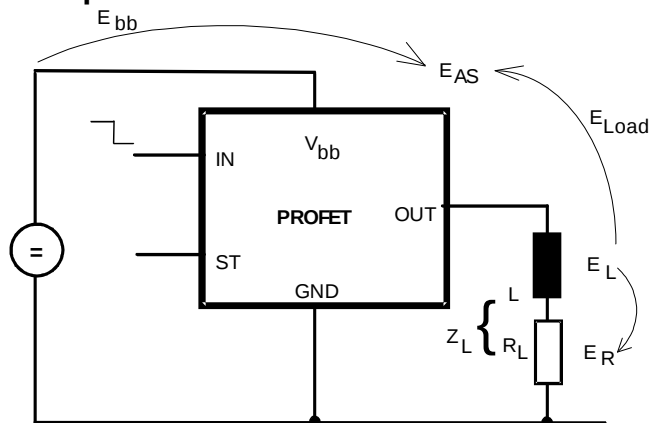
Normal load current can be handled by the PROFET itself.

### V<sub>bb</sub> disconnect with charged external inductive load



If other external inductive loads  $L$  are connected to the PROFET, additional elements like  $D$  are necessary.

### Inductive Load switch-off energy dissipation



Energy stored in load inductance:

$$E_L = \frac{1}{2} \cdot L \cdot I_L^2$$

While demagnetizing load inductance, the energy dissipated in PROFET is

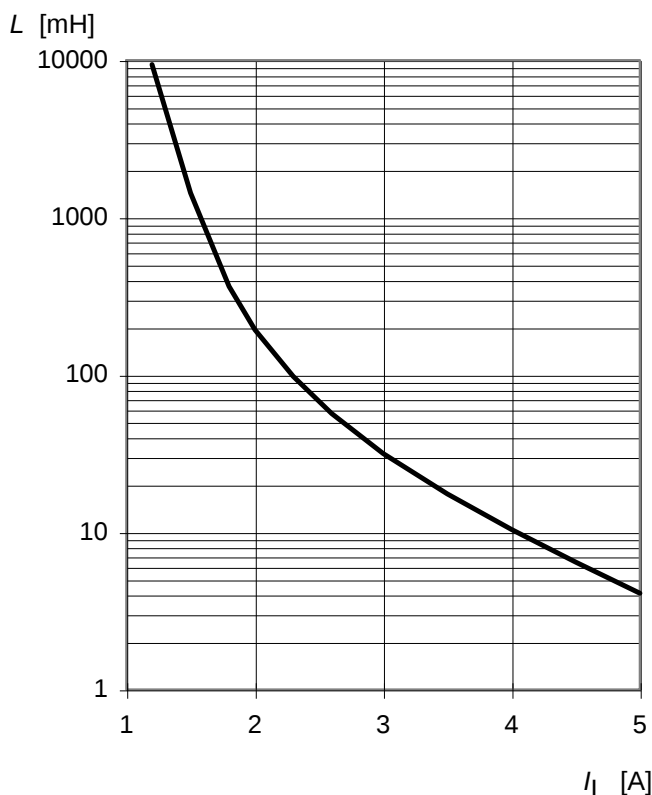
$$E_{AS} = E_{bb} + E_L - E_R = \int V_{ON(CL)} \cdot i_L(t) dt,$$

with an approximate solution for  $R_L > 0 \Omega$ :

$$E_{AS} = \frac{I_L \cdot L}{2 \cdot R_L} \cdot (V_{bb} + |V_{OUT(CL)}|) \cdot \ln \left( 1 + \frac{I_L \cdot R_L}{|V_{OUT(CL)}|} \right)$$

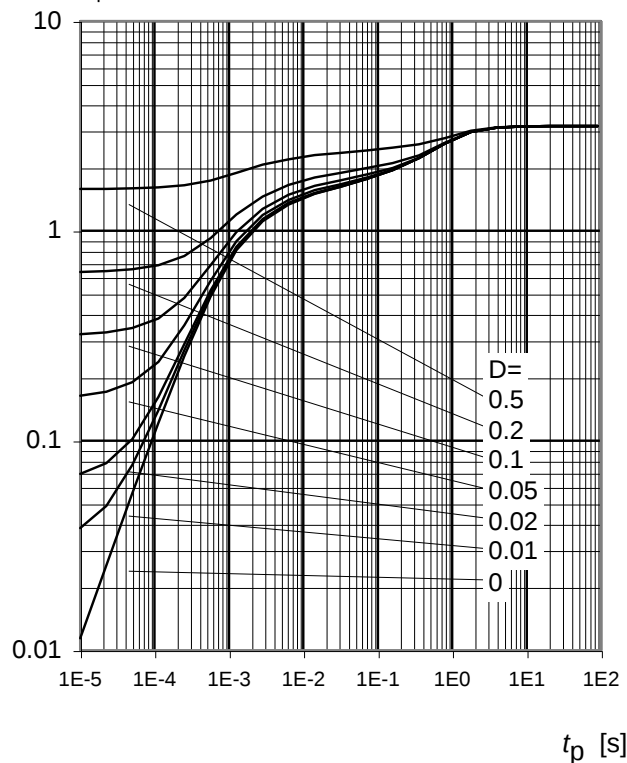
### Maximum allowable load inductance for a single switch off

$L = f(I_L)$ ;  $T_{j,start} = 150^\circ\text{C}$ ,  $T_C = 150^\circ\text{C}$  const.,  
 $V_{bb} = 12\text{ V}$ ,  $R_L = 0 \Omega$



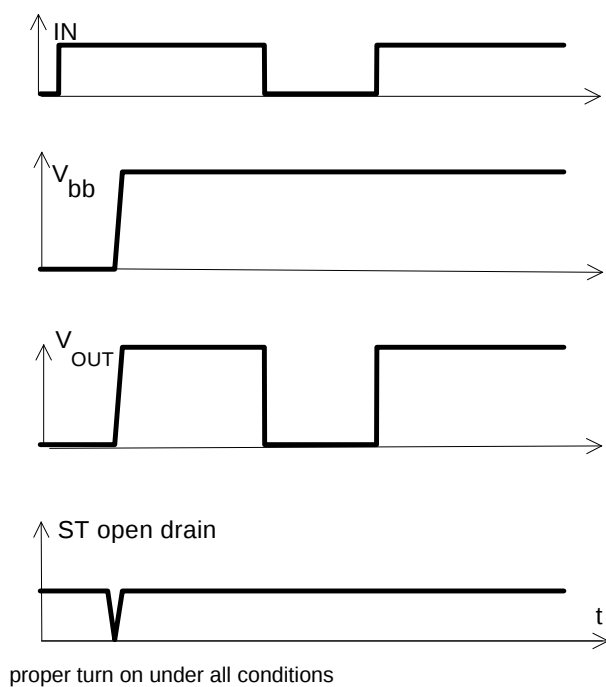
### Transient thermal impedance chip case

$Z_{thJC} = f(t_p) Z_{thJC} [\text{K/W}]$

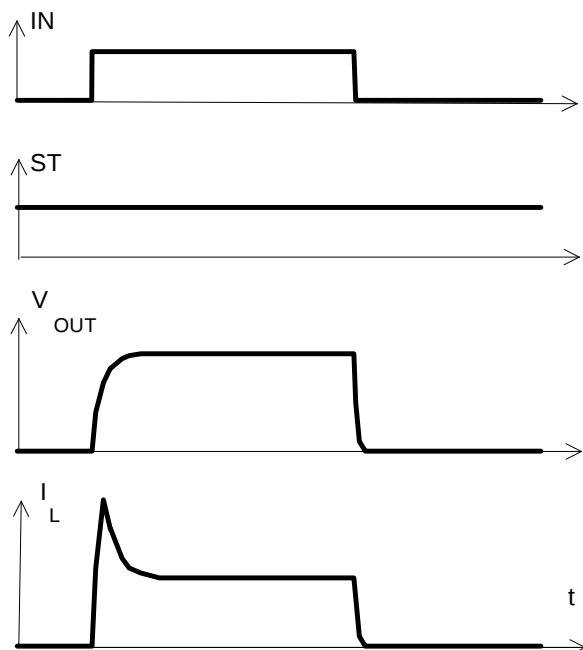


## Timing diagrams

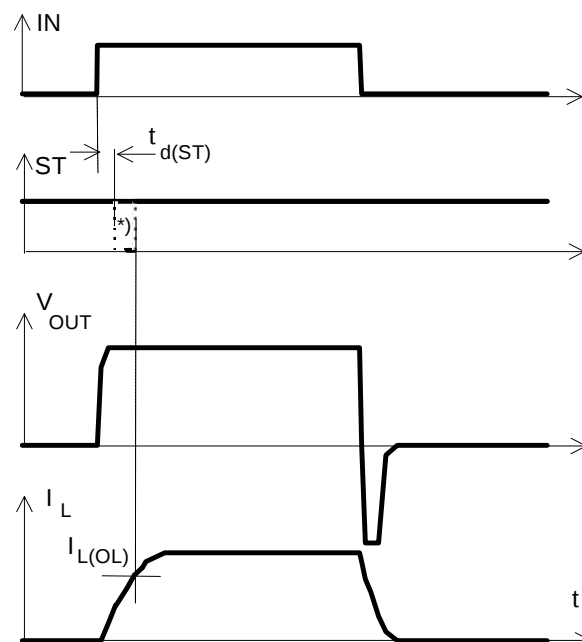
**Figure 1a:**  $V_{bb}$  turn on:



**Figure 2a:** Switching a lamp,

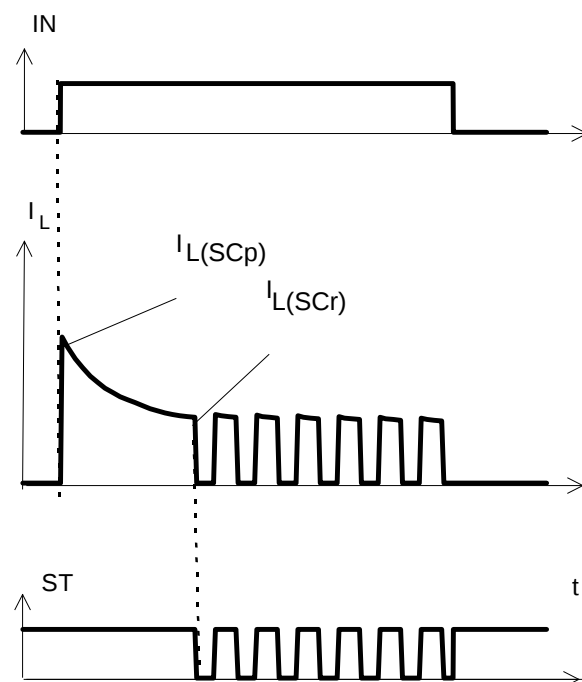


**Figure 2b:** Switching an inductive load



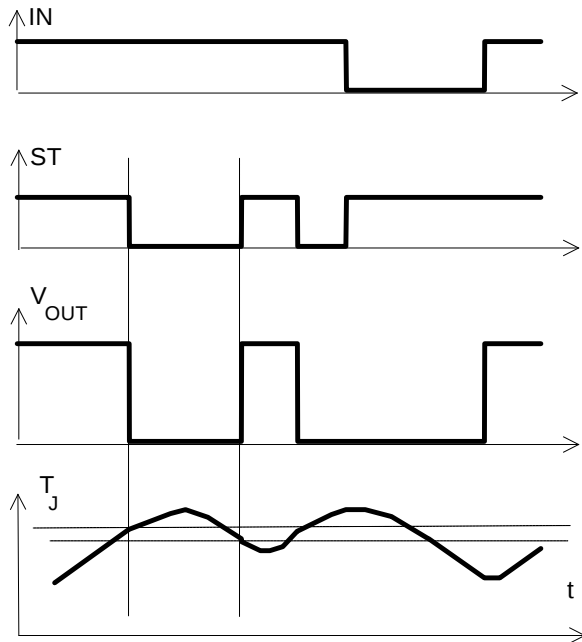
\*) if the time constant of load is too large, open-load-status may occur

**Figure 3a:** Short circuit  
shut down by overtemperature, reset by cooling

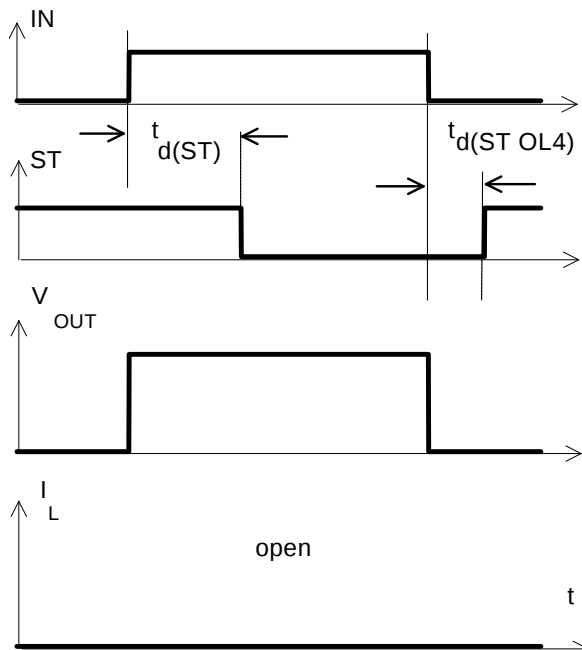


Heating up may require several milliseconds, depending on external conditions

**Figure 4a:** Overtemperature:  
Reset if  $T_j < T_{jt}$

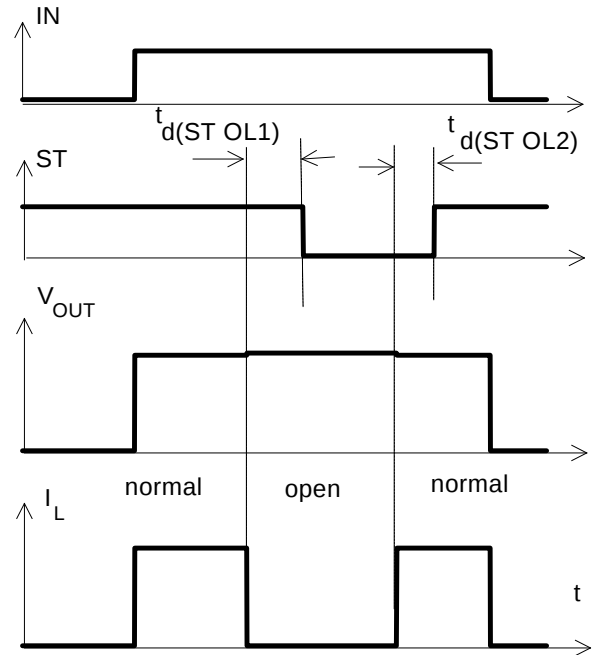


**Figure 5a:** Open load: detection in ON-state, turn on/off to open load



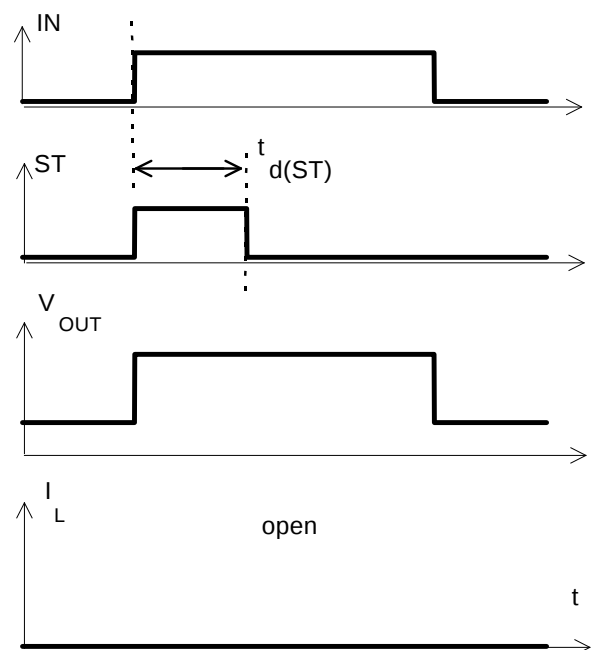
The status delay time  $t_{d(ST OL4)}$  allows to distinguish between the failure modes "open load" and "overtemperature".

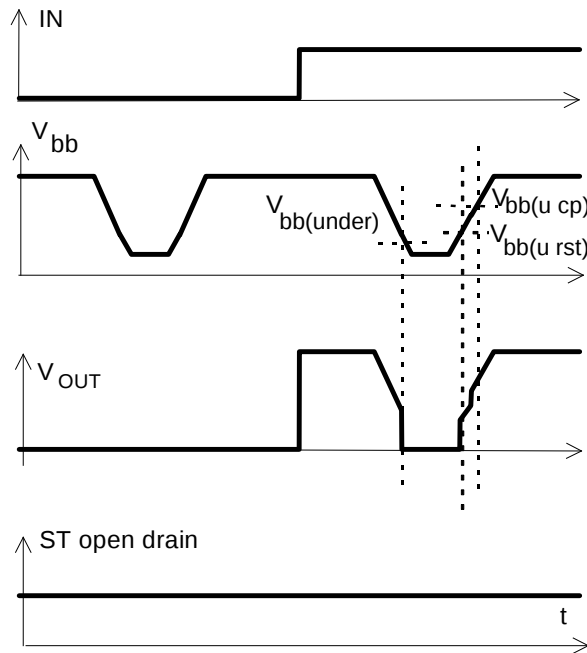
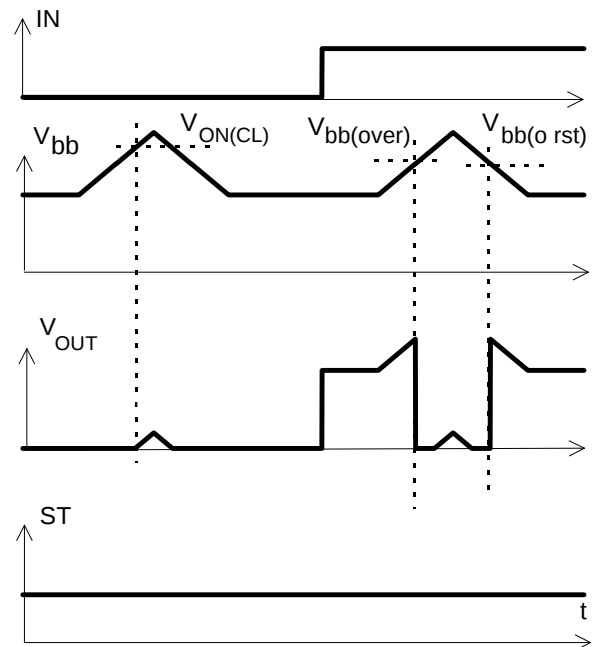
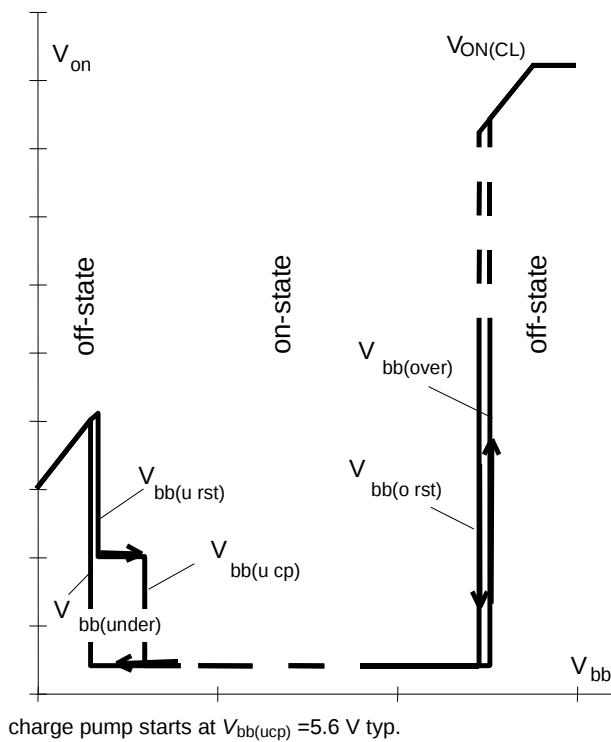
**Figure 5b:** Open load: detection in ON-state, open load occurs in on-state



$t_{d(ST OL1)} = 30 \mu s$  typ.,  $t_{d(ST OL2)} = 20 \mu s$  typ

**Figure 5c:** Open load: detection in ON- and OFF-state (with  $R_{EXT}$ ), turn on/off to open load



**Figure 6a: Undervoltage:**

**Figure 7a: Overvoltage:**

**Figure 6b: Undervoltage restart of charge pump**


## Package and Ordering Code

All dimensions in mm

**PG-TO263-5-2**

Ordering code

|                 |             |
|-----------------|-------------|
| BTS409L1 E3062A | SP001104814 |
|-----------------|-------------|

Published by

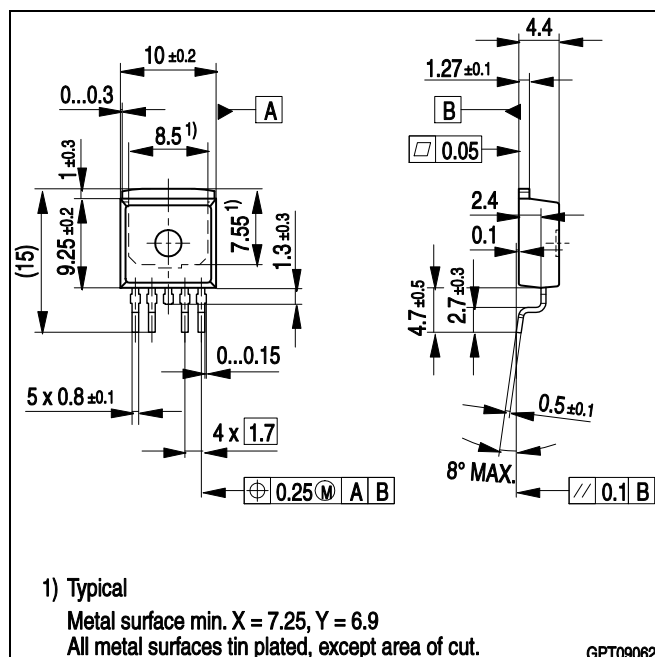
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