

Smart Two Channel 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 protection¹⁾
- Undervoltage and overvoltage shutdown with auto-restart and hysteresis
- Open drain diagnostic output
- Open load detection in OFF-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 | |
| | channels: | each | both parallel | |
| On-state resistance | R_{ON} | 200 | 100 | mΩ |
| Load current (ISO) | $I_{L(ISO)}$ | 2.3 | 4.4 | A |
| Current limitation | $I_{L(SCr)}$ | 4 | 4 | A |

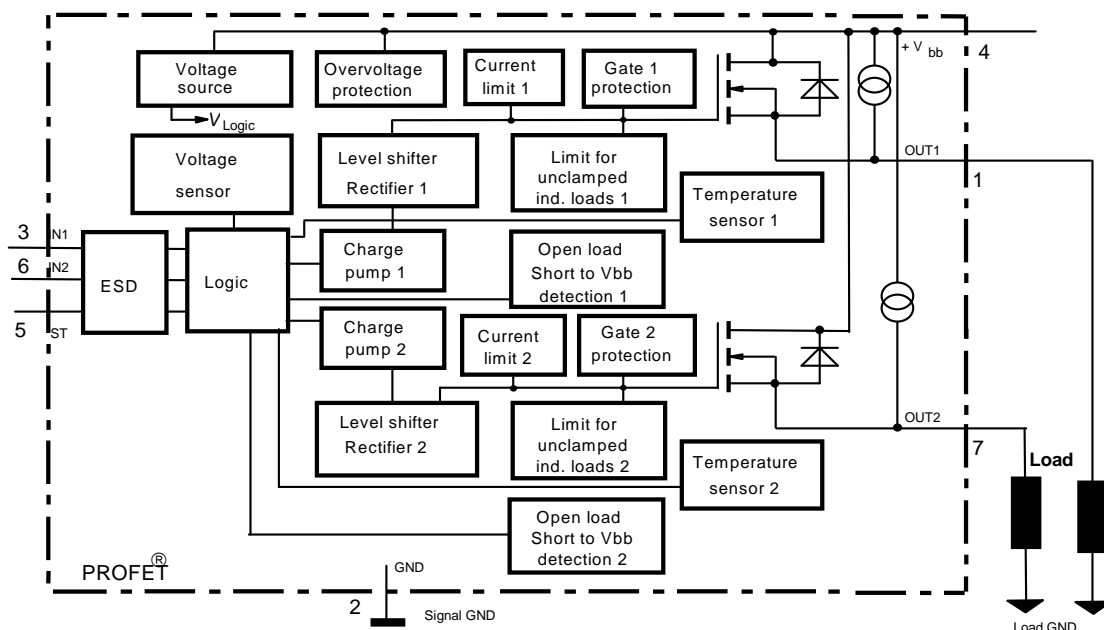


Application

- μ 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. Providing embedded protective functions.



¹⁾ 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 | OUT1 (Load, L) | Output 1, protected high-side power output of channel 1 |
| 2 | GND | Logic ground |
| 3 | IN1 | Input 1, activates channel 1 in case of logical high signal |
| 4 | V _{bb} | Positive power supply voltage, the tab is shorted to this pin |
| 5 | ST | Diagnostic feedback: open drain, low on failure |
| 6 | IN2 | Input 2, activates channel 2 in case of logical high signal |
| 7 | OUT2 (Load, L) | Output 2, protected high-side power output of channel 2 |

| 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 $T_{j\text{ start}} = -40 \dots +150\text{ °C}$ | V_{bb} | 34 | V | |
| Load dump protection ²⁾ $V_{\text{Load Dump}} = U_A + V_s$, $U_A = 13.5\text{ V}$ $R_i^3 = 2\ \Omega$, $R_L = 5.3\ \Omega$, $t_d = 200\text{ ms}$, 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_{stg} | -55 ... +150 | | |
| Power dissipation (DC), $T_C \leq 25\text{ °C}$ | P_{tot} | 36 | W | |
| Inductive load switch-off energy dissipation, single pulse $V_{bb} = 12\text{ V}$, $T_{j,\text{start}} = 150\text{ °C}$, $T_C = 150\text{ °C}$ const. one channel, $I_L = 2.3\text{ A}$, $Z_L = 89\text{ mH}$, $0\ \Omega$: | E_{AS} | 290 | mJ | |
| | | both channels parallel, $I_L = 4.4\text{ A}$, $Z_L = 47\text{ mH}$, $0\ \Omega$: | 580 | |
| see diagrams on page 9 | | | | |
| Electrostatic discharge capability (ESD) (Human Body Model) acc. MIL-STD883D, method 3015.7 and ESD assn. std. S5.1-1993 | IN: all other pins: | V_{ESD} | 1.0 2.0 | kV |
| Input voltage (DC) | V_{IN} | -10 ... +16 | V | |
| Current through input pin (DC) | I_{IN} | ± 2.0 | mA | |
| Current through status pin (DC) | I_{ST} | ± 5.0 | | |
| see internal circuit diagrams page 7 | | | | |

²⁾ Supply voltages higher than $V_{bb(AZ)}$ require an external current limit for the GND and status pins, e.g. with a $150\ \Omega$ 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.

³⁾ R_i = internal resistance of the load dump test pulse generator

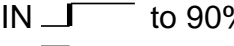
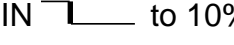
⁴⁾ $V_{\text{Load dump}}$ is setup without the DUT connected to the generator per ISO 7637-1 and DIN 40839

| Thermal Characteristics | | | | | |
|---|------------|--------|-----|-----|------|
| Parameter and Conditions | Symbol | Values | | | Unit |
| | | min | typ | max | |
| Thermal resistance chip - case, both channels: each channel: | R_{thJC} | -- | -- | 3.5 | K/W |
| | | -- | -- | 7.0 | |
| junction - ambient (free air): | R_{thJA} | -- | -- | 75 | |
| SMD version, device on PCB ⁵⁾ : | | | 37 | | |

Electrical Characteristics

| Parameter and Conditions, each channel | Symbol | Values | | | Unit |
|---|--------|--------|-----|-----|------|
| at $T_j = 25\text{ °C}$, $V_{bb} = 12\text{ V}$ unless otherwise specified | | min | typ | max | |

Load Switching Capabilities and Characteristics

| | | | | | |
|--|---|------------|------------|------------|------|
| On-state resistance (pin 4 to 1 or 7) $I_L = 1.8\text{ A}$ each channel | $T_j = 25\text{ °C}$: $T_j = 150\text{ °C}$: R_{ON} | -- | 160 320 | 200 400 | mΩ |
| Nominal load current, ISO Norm (pin 4 to 1 or 7) $V_{ON} = 0.5\text{ V}$, $T_C = 85\text{ °C}$ each channel: both channels parallel: | $I_{L(ISO)}$ | 1.8 3.5 | 2.3 4.4 | -- -- | A |
| Output current (pin 1 or 7) while GND disconnected or GND pulled up, $V_{bb} = 30\text{ V}$, $V_{IN} = 0$, see diagram page 8 | $I_{L(GNDhigh)}$ | -- | -- | 10 | mA |
| Turn-on time IN  to 90% V_{OUT} : | t_{on} | 80 | 200 | 400 | μs |
| Turn-off time IN  to 10% V_{OUT} : $R_L = 12\text{ Ω}$, $T_j = -40\dots+150\text{ °C}$ | t_{off} | 80 | 200 | 400 | |
| Slew rate on 10 to 30% V_{OUT} , $R_L = 12\text{ Ω}$, $T_j = -40\dots+150\text{ °C}$ | dV/dt_{on} | 0.1 | -- | 1 | V/μs |
| Slew rate off 70 to 40% V_{OUT} , $R_L = 12\text{ Ω}$, $T_j = -40\dots+150\text{ °C}$ | $-dV/dt_{off}$ | 0.1 | -- | 1 | V/μs |

⁵⁾ Device on 50mm*50mm*1.5mm epoxy PCB FR4 with 6cm² (one layer, 70μm thick) copper area for V_{bb} connection. PCB is vertical without blown air.

| Parameter and Conditions, each channel at $T_j = 25\text{ °C}$, $V_{bb} = 12\text{ V}$ unless otherwise specified | Symbol | Values | | | Unit |
|---|--|--------|-----|------------|---------------|
| | | min | typ | max | |
| Operating Parameters | | | | | |
| Operating voltage ⁶⁾ | $T_j = -40\dots+150\text{ °C}$: $V_{bb(\text{on})}$ | 5.0 | -- | 34 | V |
| Undervoltage shutdown | $T_j = -40\dots+150\text{ °C}$: $V_{bb(\text{under})}$ | 3.5 | -- | 5.0 | V |
| Undervoltage restart | $T_j = -40\dots+25\text{ °C}$: $V_{bb(\text{u rst})}$ $T_j = +150\text{ °C}$: | -- | -- | 5.0 7.0 | V |
| Undervoltage restart of charge pump see diagram page 12 | $V_{bb(\text{ucp})}$ | -- | 5.6 | 7.0 | V |
| Undervoltage hysteresis $\Delta V_{bb(\text{under})} = V_{bb(\text{u rst})} - V_{bb(\text{under})}$ | $\Delta V_{bb(\text{under})}$ | -- | 0.2 | -- | V |
| Overvoltage shutdown | $T_j = -40\dots+150\text{ °C}$: $V_{bb(\text{over})}$ | 34 | -- | 43 | V |
| Overvoltage restart | $T_j = -40\dots+150\text{ °C}$: $V_{bb(\text{o rst})}$ | 33 | -- | -- | V |
| Overvoltage hysteresis | $T_j = -40\dots+150\text{ °C}$: $\Delta V_{bb(\text{over})}$ | -- | 0.5 | -- | V |
| Overvoltage protection ⁷⁾ $I_{bb}=40\text{ mA}$ | $T_j = -40\dots+150\text{ °C}$: $V_{bb(\text{AZ})}$ | 42 | 47 | -- | V |
| Standby current (pin 4), $V_{IN}=0$ | $T_j=-40\dots+150\text{ °C}$: $I_{bb(\text{off})}$ | -- | 90 | 150 | μA |
| Operating current (Pin 2) ⁸⁾ , $V_{IN}=5\text{ V}$ both channels on, $T_j = -40\dots+150\text{ °C}$, | I_{GND} | -- | 0.6 | 1.2 | mA |
| Operating current (Pin 2) ⁸⁾ one channel on, $T_j = -40\dots+150\text{ °C}$; | I_{GND} | -- | 0.4 | 0.7 | mA |

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



⁷⁾ See also $V_{\text{ON}(\text{CL})}$ in table of protection functions and circuit diagram page 8.

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

| Parameter and Conditions, each channel at $T_j = 25\text{ °C}$, $V_{bb} = 12\text{ V}$ unless otherwise specified | Symbol | Values | | | Unit |
|---|-----------------|-------------------|-------------------|---------------|------|
| | | min | typ | max | |
| Protection Functions⁹⁾ | | | | | |
| Initial peak short circuit current limit (pin 4 to 1 or 7) | $I_{L(SCp)}$ | | | | |
| $T_j = -40\text{ °C}$: $T_j = 25\text{ °C}$: $T_j = +150\text{ °C}$: | | 5.5 4.5 2.5 | 9.5 7.5 4.5 | 13 11 7 | A |
| Repetitive short circuit shutdown current limit | $I_{L(SCr)}$ | | | | |
| $T_j = T_{jt}$ (see timing diagrams, page 12) | | -- | 4 | -- | A |
| Output clamp (inductive load switch off) at $V_{OUT} = V_{bb} - V_{ON(CL)}$ $I_L = 40\text{ mA}$: | $V_{ON(CL)}$ | 41 | 47 | 53 | V |
| Thermal overload trip temperature | T_{jt} | 150 | -- | -- | °C |
| Thermal hysteresis | ΔT_{jt} | -- | 10 | -- | K |
| Reverse battery (pin 4 to 2) ¹⁰⁾ | $-V_{bb}$ | -- | -- | 32 | V |
| Reverse battery voltage drop ($V_{out} > V_{bb}$) $I_L = -1.9\text{ A}$, each channel $T_j = 150\text{ °C}$: | $-V_{ON(rev)}$ | -- | 610 | -- | mV |
| Diagnostic Characteristics | | | | | |
| Open load detection current (included in standby current $I_{bb(off)}$) | $I_{L(off)}$ | -- | 30 | -- | μA |
| Open load detection voltage $T_j = -40..150\text{ °C}$: | $V_{OUT(OL)}$ | 2 | 3 | 4 | V |

⁹⁾ 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.

¹⁰⁾ Requires 150 Ω 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).

| Parameter and Conditions, each channel at $T_j = 25\text{ °C}$, $V_{bb} = 12\text{ V}$ unless otherwise specified | Symbol | Values | | | Unit |
|--|--------------------|--------|-----|-----|------------------|
| | | min | typ | max | |
| Input and Status Feedback¹¹⁾ | | | | | |
| Input resistance $T_j = -40..150\text{ °C}$, see circuit page 7 | R_i | 2.5 | 3.5 | 6 | $\text{k}\Omega$ |
| Input turn-on threshold voltage  T_j | $V_{IN(T+)}$ | 1.7 | -- | 3.5 | V |
| Input turn-off threshold voltage  $T_j = -40$ | $V_{IN(T-)}$ | 1.5 | -- | -- | V |
| Input threshold hysteresis | $\Delta V_{IN(T)}$ | -- | 0.5 | -- | V |
| Off state input current (pin 3 or 6), $V_{IN} = 0.4\text{ V}$, $T_j = -40..+150\text{ °C}$ | $I_{IN(off)}$ | 1 | -- | 50 | μA |
| On state input current (pin 3 or 6), $V_{IN} = 3.5\text{ V}$, $T_j = -40..+150\text{ °C}$ | $I_{IN(on)}$ | 20 | 50 | 90 | μA |
| Delay time for status with open load after Input neg. slope (see diagram page 12) | $t_{d(ST\ OL3)}$ | -- | 220 | -- | μs |
| Status output (open drain) | | | | | |
| Zener limit voltage $T_j = -40...+150\text{ °C}$, $I_{ST} = +1.6\text{ mA}$: | $V_{ST(high)}$ | 5.4 | 6.1 | -- | V |
| ST low voltage $T_j = -40...+25\text{ °C}$, $I_{ST} = +1.6\text{ mA}$: | $V_{ST(low)}$ | -- | -- | 0.4 | |
| $T_j = +150\text{ °C}$, $I_{ST} = +1.6\text{ mA}$: | | -- | -- | 0.6 | |

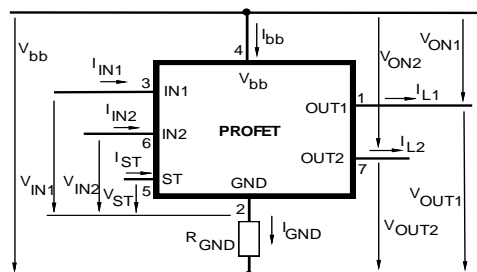
¹¹⁾ If a ground resistor R_{GND} is used, add the voltage drop across this resistor.

Truth Table

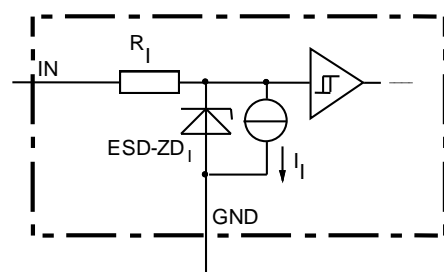
| | | IN1 | IN2 | OUT1 | OUT2 | ST | ST |
|--|--------------|-----|-----|------|------|---------------------|----------|
| | | | | | | BTS611L1 | BTS612N1 |
| Normal operation | | L | L | L | L | H | H |
| | | L | H | L | H | H | H |
| | | H | L | H | L | H | H |
| | | H | H | H | H | H | H |
| Open load | Channel 1 | L | L | Z | L | H(L ¹²) | L |
| | | L | H | Z | H | H | H |
| | | H | X | H | X | L | H |
| | Channel 2 | L | L | L | Z | H(L ¹²) | L |
| | | H | L | H | Z | H | H |
| | | X | H | X | H | L | H |
| Short circuit to V_{bb} | Channel 1 | L | L | H | L | L ¹³ | L |
| | | L | H | H | H | H | H |
| | | H | X | H | X | H(L ¹⁴) | H |
| | Channel 2 | L | L | L | H | L ¹³ | L |
| | | H | L | H | H | H | H |
| | | X | H | X | H | H(L ¹⁴) | H |
| Overtemperature | both channel | L | L | L | L | H | H |
| | | X | H | L | L | L | L |
| | | H | X | L | L | L | L |
| | Channel 1 | L | X | L | X | H | H |
| | | H | X | L | X | L | L |
| | Channel 2 | X | L | X | L | H | H |
| X | | H | X | L | L | L | |
| Undervoltage/ Overvoltage | | X | X | L | L | H | H |

L = "Low" Level X = don't care Z = high impedance, potential depends on external circuit
H = "High" Level Status signal after the time delay shown in the diagrams (see fig 5. page 12)

Terms



Input circuit (ESD protection)



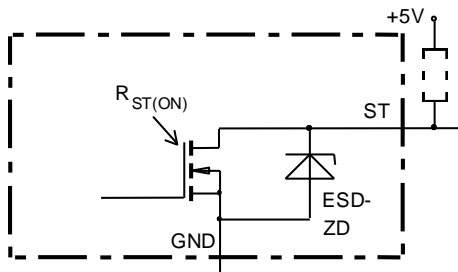
ESD zener diodes are not to be used as voltage clamp at DC conditions. Operation in this mode may result in a drift of the zener voltage (increase of up to 1 V).

¹²⁾ With additional external pull up resistor

¹³⁾ 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 $V_{ST\ low}$ signal may be erroneous.

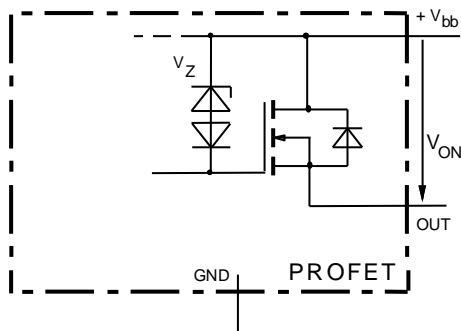
¹⁴⁾ Low resistance to V_{bb} may be detected in the ON-state by the no-load-detection

Status output



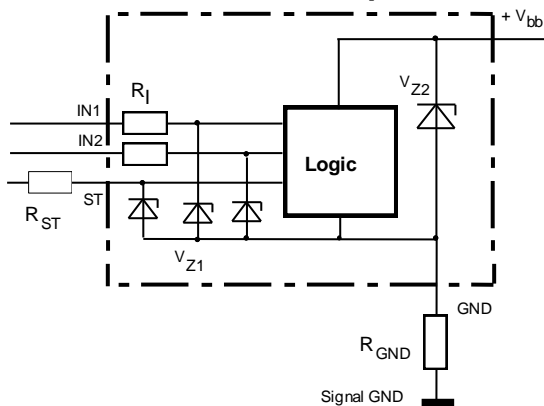
ESD-Zener diode: 6.1 V typ., max 5 mA;
 $R_{ST(ON)} < 380 \Omega$ at 1.6 mA, ESD zener diodes are not to be used as voltage clamp at DC conditions.
 Operation in this mode may result in a drift of the zener voltage (increase of up to 1 V).

Inductive and overvoltage output clamp



V_{ON} clamped to 47 V typ.

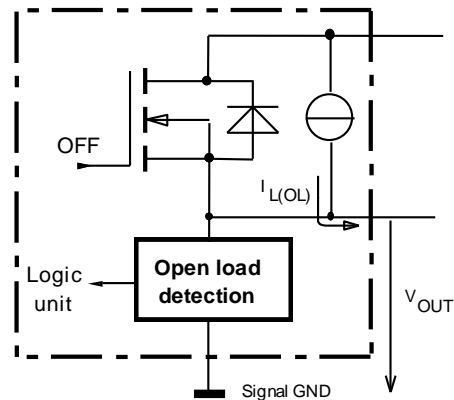
Overvolt. and reverse batt. protection



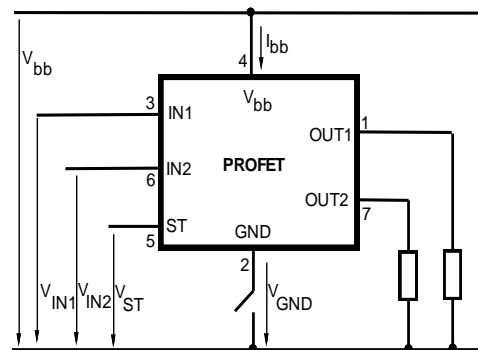
$V_{Z1} = 6.1 \text{ V typ.}$, $V_{Z2} = 47 \text{ V typ.}$, $R_1 = 3.5 \text{ k}\Omega \text{ typ.}$, $R_{GND} = 150 \Omega$

Open-load detection

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

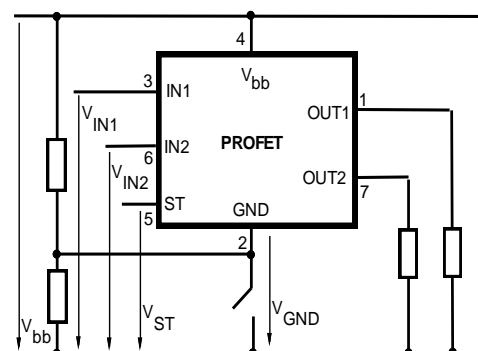


GND disconnect



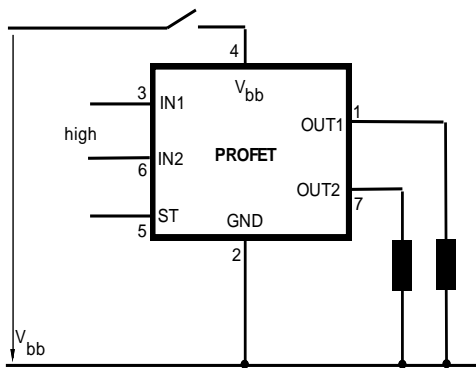
Any kind of load. In case of Input=high is $V_{OUT} \approx V_{IN} - V_{IN(T+)}$.
 Due to $V_{GND} > 0$, no $V_{ST} = \text{low}$ signal available.

GND disconnect with GND pull up



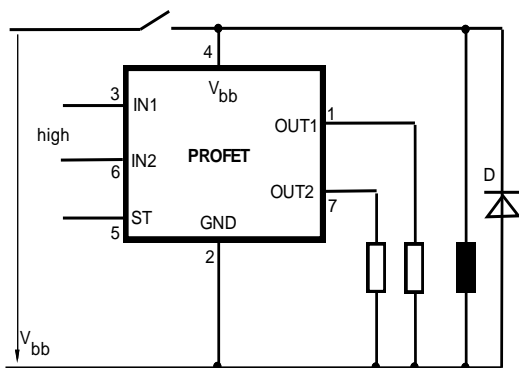
Any kind of load. If $V_{GND} > V_{IN} - V_{IN(T+)}$ device stays off
 Due to $V_{GND} > 0$, no $V_{ST} = \text{low}$ signal available.

V_{bb} disconnect with energized inductive load



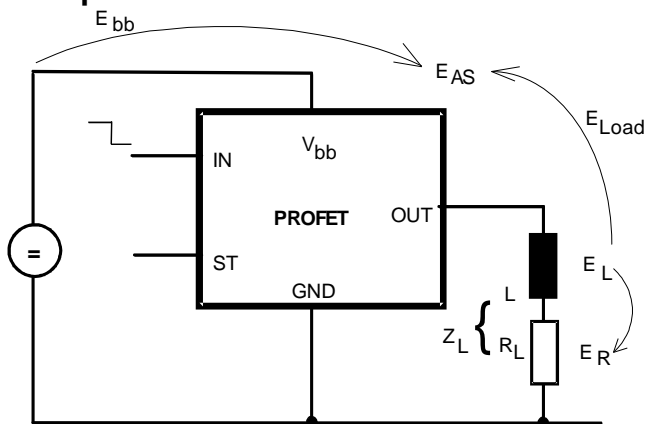
Normal load current can be handled by the PROFET itself.

V_{bb} 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 $R_L > 0 \Omega$:

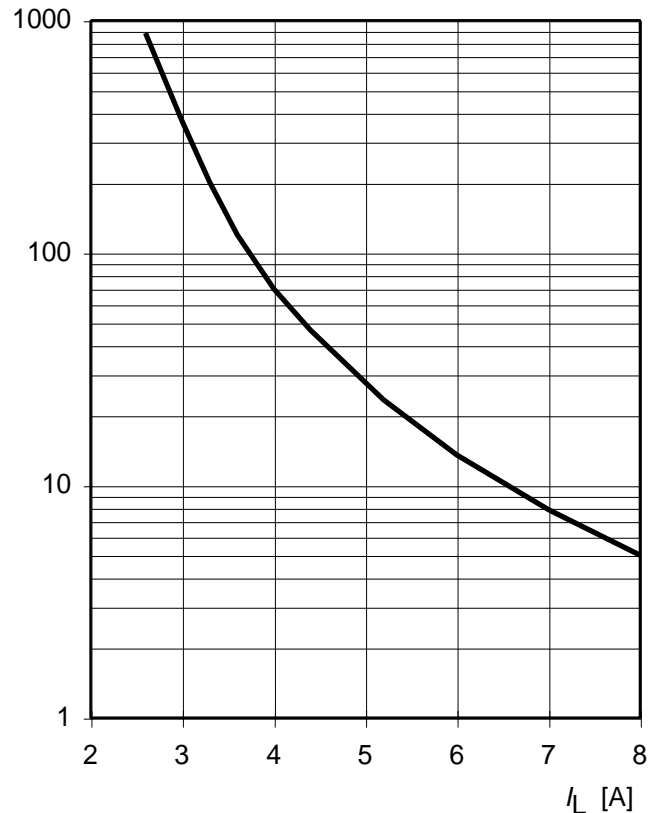
$$E_{AS} = \frac{I_L \cdot L}{2 \cdot R_L} \cdot (V_{bb} + |V_{OUT(CL)}|) \cdot \ln \left(1 + \frac{I_L \cdot R_L}{|V_{OUT(CL)}|} \right)$$

Maximum allowable load inductance for a single switch off (both channels parallel)

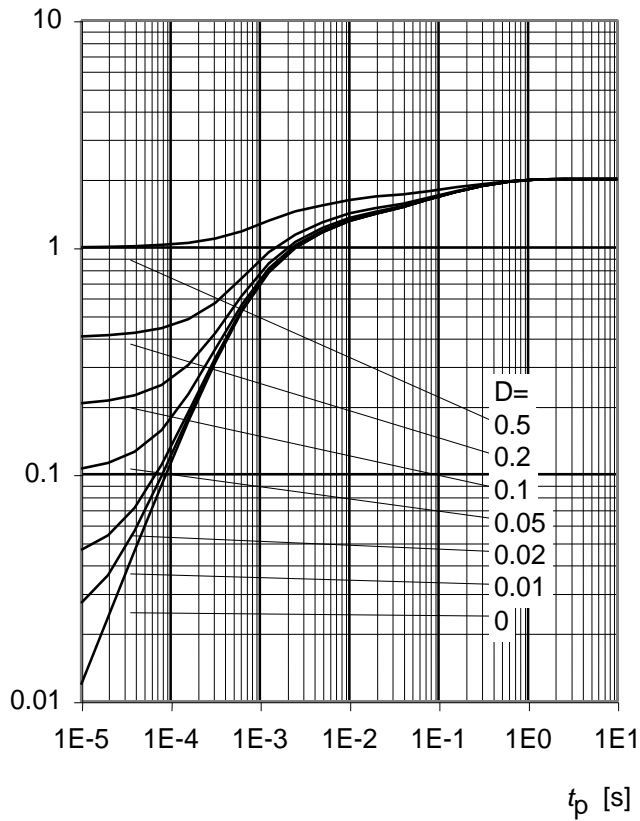
$L = f(I_L)$; $T_{j,start} = 150^\circ\text{C}$, $T_C = 150^\circ\text{C}$ const.,

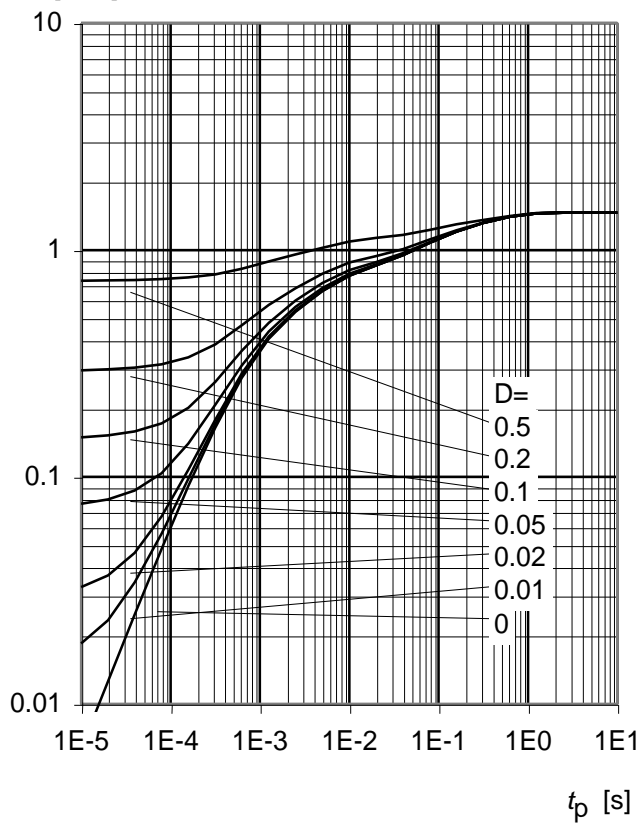
$V_{bb} = 12\text{V}$, $R_L = 0 \Omega$

L [mH]



Typ. transient thermal impedance chip case
 $Z_{thJC} = f(t_p)$, one Channel active

 Z_{thJC} [K/W]

Transient thermal impedance chip case
 $Z_{thJC} = f(t_p)$, both Channel active

 Z_{thJC} [K/W]


Timing diagrams

Both channels are symmetric and consequently the diagrams are valid for each channel as well as for permuted channels

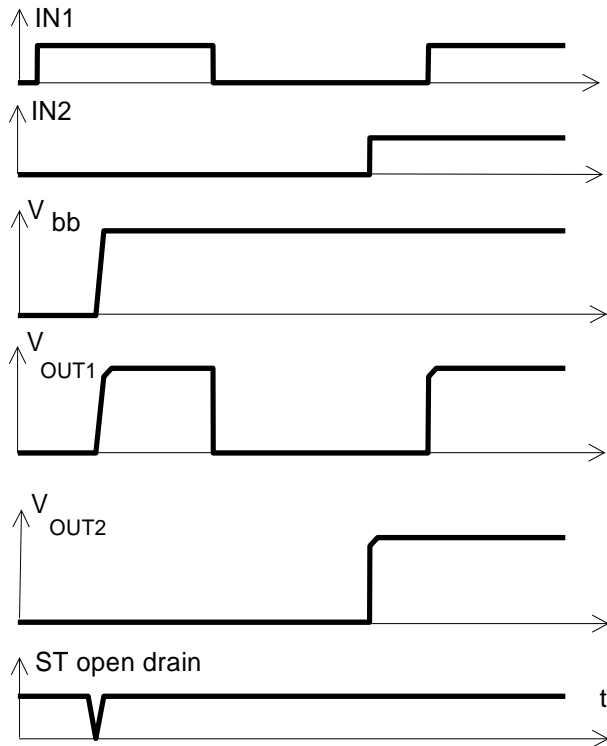
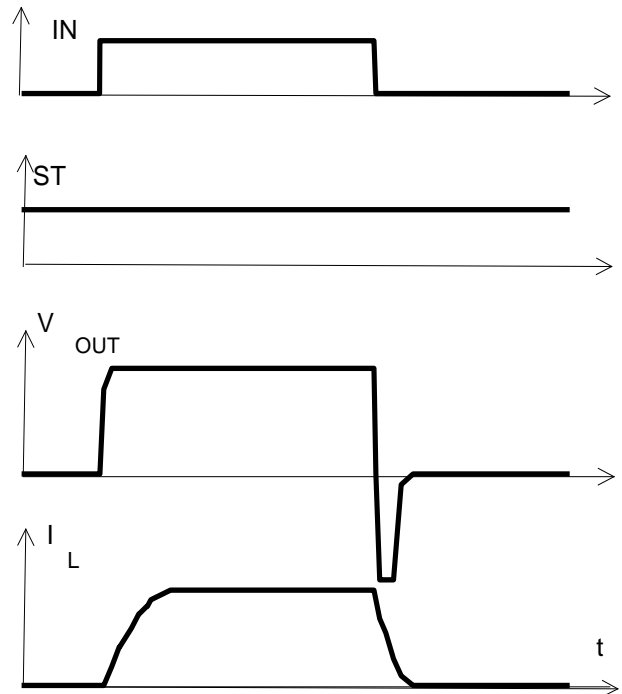
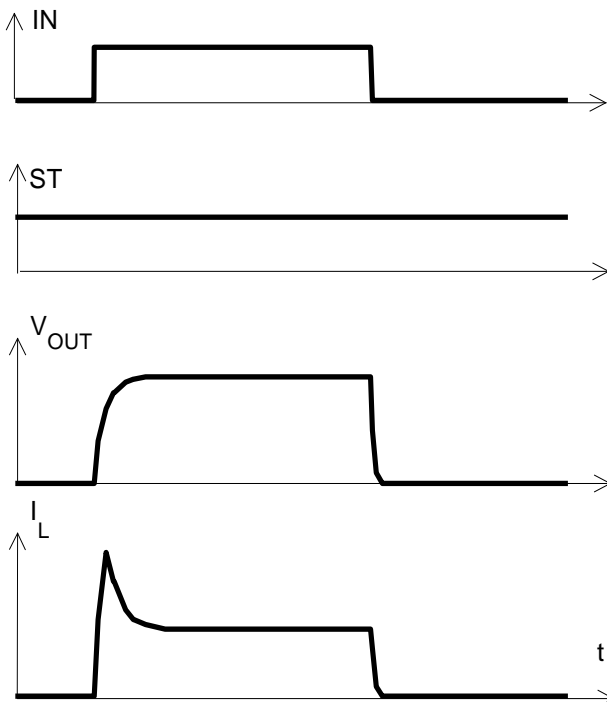
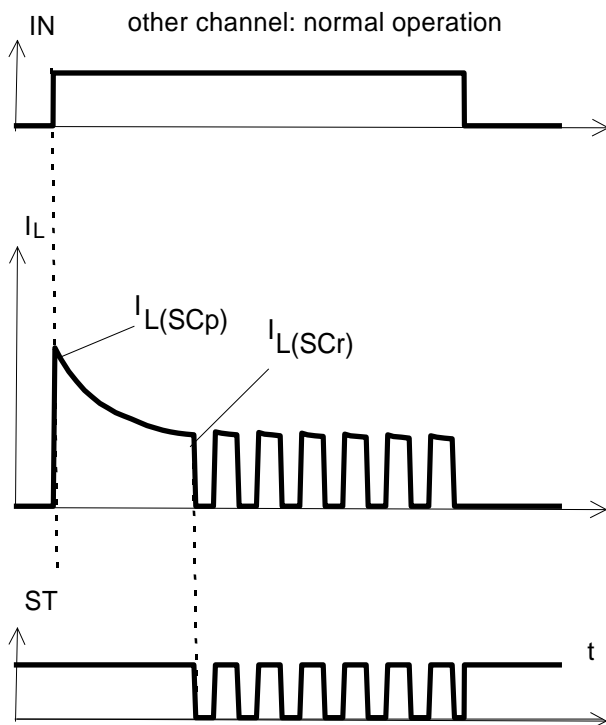
Figure 1a: V_{bb} turn on:

Figure 2b: Switching an inductive load

Figure 2a: Switching a lamp:


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 $T_j < T_{jt}$

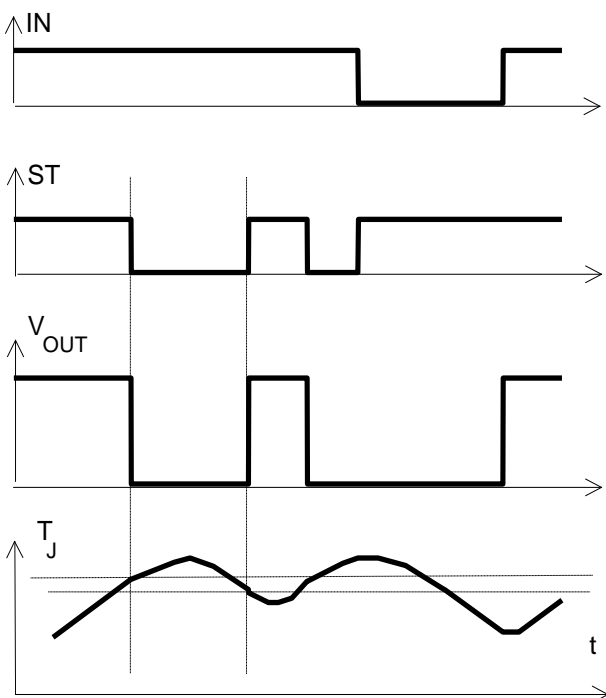
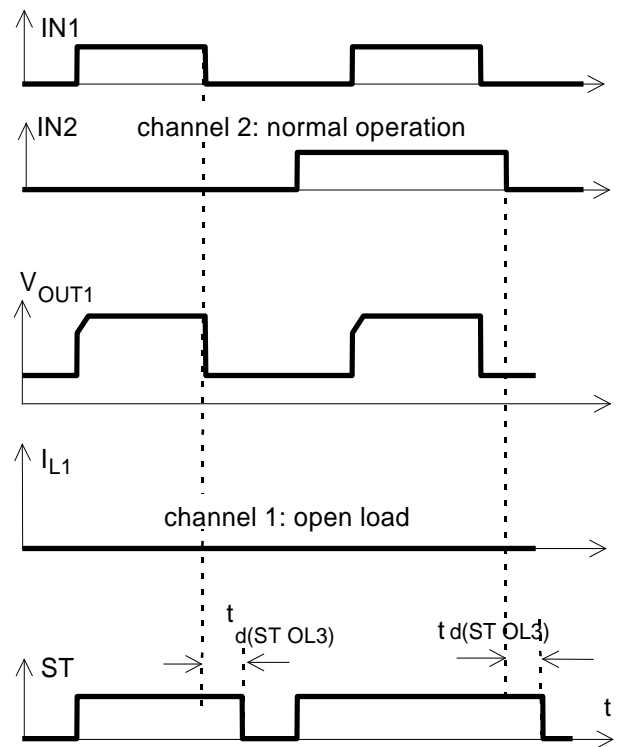


Figure 5a: Open load: detection in OFF-state, turn on/off to open load



$t_{d(ST,OL3)}$ depends on external circuitry because of high impedance

*) $I_L = 30 \mu A$ typ

Figure 6a: Undervoltage:

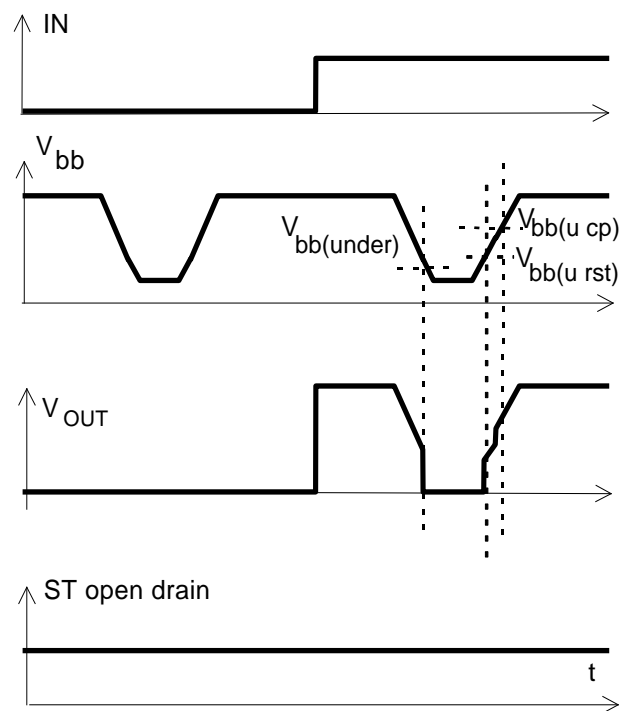
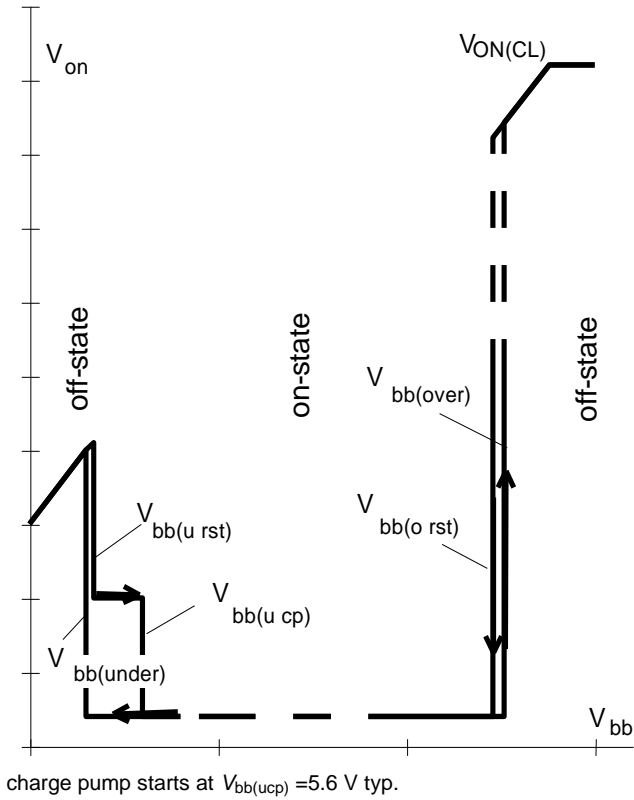
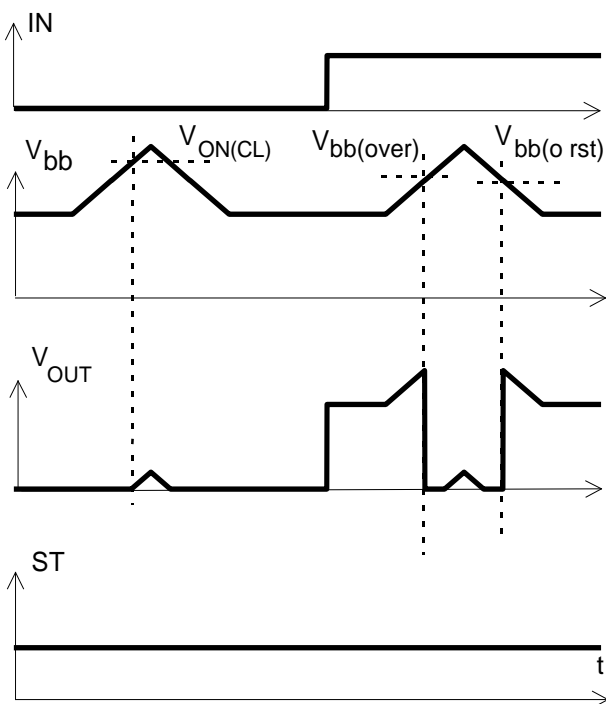


Figure 6b: Undervoltage restart of charge pump

Figure 7a: Overvoltage:


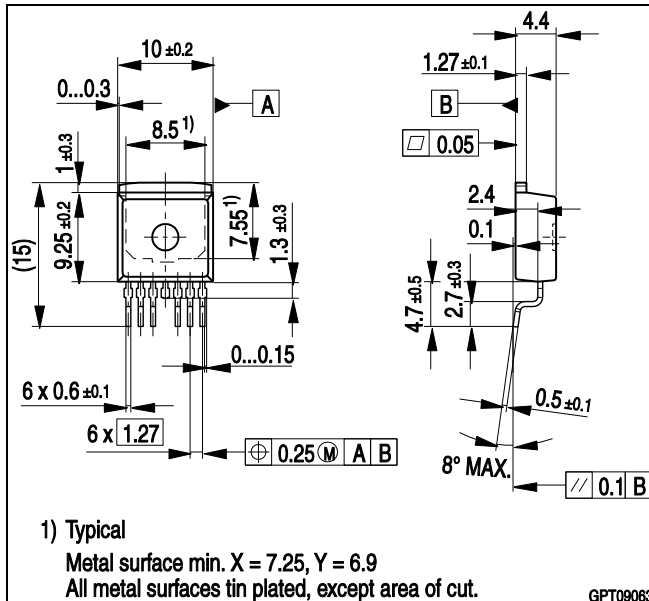
Package and Ordering Code

All dimensions in mm

PG-TO263-7-2

Ordering code

| | |
|-----------------|-------------|
| BTS612N1 E3128A | SP001104824 |
|-----------------|-------------|



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