

## Smart Highside 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
- CMOS diagnostic output
- Open load detection in ON-state
- CMOS compatible input
- Loss of ground and loss of  $V_{bb}$  protection<sup>2)</sup>
- Electrostatic discharge (ESD) protection

### Product Summary

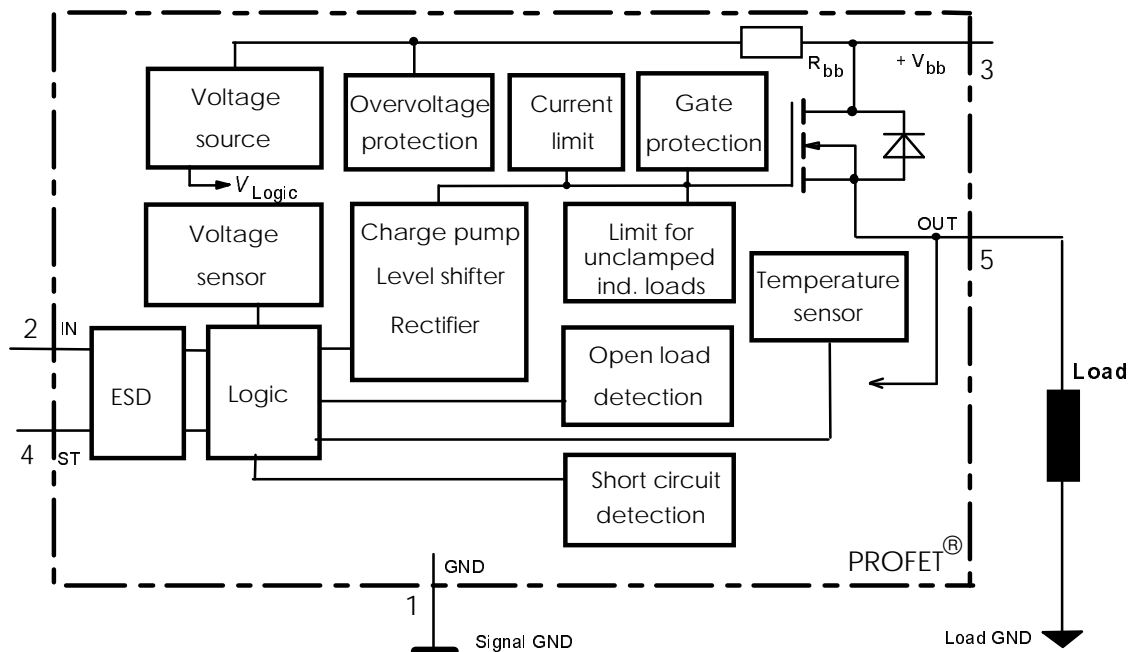
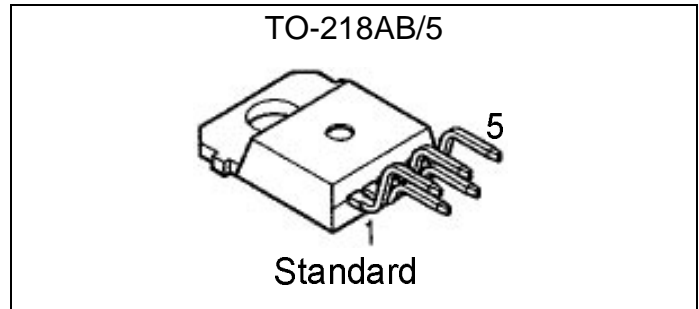
Overvoltage protection	$V_{bb(AZ)}$	63	V
Operating voltage	$V_{bb(on)}$	4.5 ... 42	V
On-state resistance	$R_{ON}$	18	m $\Omega$
Load current (ISO)	$I_L(ISO)$	21	A
Current limitation	$I_L(SCr)$	70	A

### 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 and discrete circuits

### General Description

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



1) No external components required, reverse load current limited by connected load.

2) Additional external diode required for charged inductive loads

Pin	Symbol		Function
1	GND	-	Logic ground
2	IN	I	Input, activates the power switch in case of logical high signal
3	V <sub>bb</sub>	+	Positive power supply voltage, the tab is shorted to this pin
4	ST	S	Diagnostic feedback, low on failure
5	OUT (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 3)	$V_{bb}$	63	V
Load dump protection $V_{LoadDump} = U_A + V_S$ , $U_A = 13.5\text{ V}$ $R_I = 2\ \Omega$ , $R_L = 1.1\ \Omega$ , $t_d = 200\text{ ms}$ , IN= low or high	$V_{Load\ dump}^{3)}$	80	V
Load current (Short-circuit current, see page 4)	$I_L$	self-limited	A
Operating temperature range	$T_j$	-40 ... +150	°C
Storage temperature range	$T_{stg}$	-55 ... +150	
Power dissipation (DC)	$P_{tot}$	167	W
Inductive load switch-off energy dissipation, single pulse $T_j = 150\text{ °C}$ :	$E_{AS}$	2.1	J
Electrostatic discharge capability (ESD) (Human Body Model)	$V_{ESD}$	2.0	kV
Input voltage (DC)	$V_{IN}$	-0.5 ... +6	V
Current through input pin (DC)	$I_{IN}$	±5.0	mA
Current through status pin (DC)	$I_{ST}$	±5.0	
see internal circuit diagrams page 6...			
Thermal resistance	chip - case:	$R_{thJC}$	≤ 0.75
	junction - ambient (free air):	$R_{thJA}$	≤ 45
			K/W

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

## Electrical Characteristics

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

## Load Switching Capabilities and Characteristics

On-state resistance (pin 3 to 5) $I_L = 5\text{ A}$	$T_j=25\text{ °C}$ : $T_j=150\text{ °C}$ :	$R_{ON}$	--	15 28	18 35	$m\Omega$
Nominal load current (pin 3 to 5) ISO Proposal: $V_{ON} = 0.5\text{ V}$ , $T_C = 85\text{ °C}$		$I_{L(ISO)}$	17	21	--	A
Output current (pin 5) while GND disconnected or GND pulled up, $V_{IN} = 0$ , see diagram page 7, $T_j = -40\dots+150\text{ °C}$		$I_{L(GNDhigh)}$	--	--	1	mA
Turn-on time to 90% $V_{OUT}$ :		$t_{on}$	100	--	350	$\mu\text{s}$
Turn-off time to 10% $V_{OUT}$ :		$t_{off}$	10	--	130	
$R_L = 12\ \Omega$ , $T_j = -40\dots+150\text{ °C}$						
Slew rate on 10 to 30% $V_{OUT}$ , $R_L = 12\ \Omega$ , $T_j = -40\dots+150\text{ °C}$		$dV/dt_{on}$	0.2	--	2	$V/\mu\text{s}$
Slew rate off 70 to 40% $V_{OUT}$ , $R_L = 12\ \Omega$ , $T_j = -40\dots+150\text{ °C}$		$-dV/dt_{off}$	0.4	--	5	$V/\mu\text{s}$

## Operating Parameters

Operating voltage <sup>4)</sup>	$T_j = -40\dots+150\text{ °C}$ :	$V_{bb(on)}$	4.5	--	42	V
Undervoltage shutdown	$T_j = -40\dots+150\text{ °C}$ :	$V_{bb(under)}$	2.4	--	4.5	V
Undervoltage restart	$T_j = -40\dots+150\text{ °C}$ :	$V_{bb(u\ rst)}$	--	--	4.5	V
Undervoltage restart of charge pump see diagram page 12	$T_j = -40\dots+150\text{ °C}$ :	$V_{bb(ucp)}$	--	6.5	7.5	V
Undervoltage hysteresis $\Delta V_{bb(under)} = V_{bb(u\ rst)} - V_{bb(under)}$		$\Delta V_{bb(under)}$	--	0.2	--	V
Overshoot shutdown	$T_j = -40\dots+150\text{ °C}$ :	$V_{bb(over)}$	42	--	52	V
Overshoot restart	$T_j = -40\dots+150\text{ °C}$ :	$V_{bb(o\ rst)}$	42	--	--	V
Overshoot hysteresis	$T_j = -40\dots+150\text{ °C}$ :	$\Delta V_{bb(over)}$	--	0.2	--	V
Overshoot protection <sup>5)</sup>	$T_j = -40\text{ °C}$ :	$V_{bb(AZ)}$	60	--	--	V
$I_{bb} = 40\text{ mA}$	$T_j = 25\dots+150\text{ °C}$ :		63	67		
Standby current (pin 3) $V_{IN} = 0$ , $I_{ST} = 0$ ,	$T_j = -40\dots+25\text{ °C}$ :	$I_{bb(off)}$	--	12	25	$\mu\text{A}$
	$T_j = 150\text{ °C}$ :		--	18	60	
Leakage output current (included in $I_{bb(off)}$ ) $V_{IN} = 0$		$I_{L(off)}$	--	6	--	$\mu\text{A}$
Operating current (Pin 1) <sup>6)</sup> , $V_{IN} = 5\text{ V}$		$I_{GND}$	--	1.1	--	mA

4) At supply voltage increase up to  $V_{bb} = 6.5\text{ V}$  typ without charge pump,  $V_{OUT} \approx V_{bb} - 2\text{ V}$

5) see also  $V_{ON(CL)}$  in table of protection functions and circuit diagram page 7. Measured without load

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

Parameter and Conditions at $T_j = 25\text{ °C}$ , $V_{bb} = 12\text{ V}$ unless otherwise specified	Symbol	Values			Unit
		min	typ	max	
<b>Protection Functions</b>					
Initial peak short circuit current limit (pin 3 to 5) <sup>7)</sup> , (max 400 $\mu\text{s}$ if $V_{ON} > V_{ON(SC)}$ )	$I_{L(SCp)}$				
$T_j = -40\text{ °C}$ : $T_j = 25\text{ °C}$ : $T_j = +150\text{ °C}$ :		-- -- 45	-- 95 --	140 -- --	A
Repetitive short circuit current limit $T_j = T_{jt}$ (see timing diagrams, page 10)	$I_{L(SCr)}$	30	70	--	A
Short circuit shutdown delay after input pos. slope $V_{ON} > V_{ON(SC)}$ , $T_j = -40..+150\text{ °C}$ : min value valid only, if input "low" time exceeds 30 $\mu\text{s}$	$t_{d(SC)}$	80	--	400	$\mu\text{s}$
Output clamp (inductive load switch off) at $V_{OUT} = V_{bb} - V_{ON(CL)}$ , $I_L = 30\text{ mA}$	$V_{ON(CL)}$	--	58	--	V
Short circuit shutdown detection voltage (pin 3 to 5)	$V_{ON(SC)}$	--	8.3	--	V
Thermal overload trip temperature	$T_{jt}$	150	--	--	$\text{°C}$
Thermal hysteresis	$\Delta T_{jt}$	--	10	--	K
Inductive load switch-off energy dissipation <sup>8)</sup> , $T_{j\text{ Start}} = 150\text{ °C}$ , single pulse	$E_{AS}$ $E_{Load12}$ $E_{Load24}$	--	--	2.1 1.7 1.2	J
$V_{bb} = 12\text{ V}$ : $V_{bb} = 24\text{ V}$ :					
Reverse battery (pin 3 to 1) <sup>9)</sup>	$-V_{bb}$	--	--	32	V
Integrated resistor in $V_{bb}$ line	$R_{bb}$	--	120	--	$\Omega$

### Diagnostic Characteristics



Open load detection current (on-condition)	$T_j = -40\text{ °C}$ : $T_j = 25..150\text{ °C}$ :	$I_{L(OL)}$	2 2	-- --	1900 1500	mA
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7) Short circuit current limit for max. duration of  $t_{d(SC)} \text{ max} = 400\text{ }\mu\text{s}$ , prior to shutdown

8) While demagnetizing load inductance, dissipated energy in PROFET is  $E_{AS} = \int V_{ON(CL)} * i_L(t) dt$ , approx.

$$E_{AS} = \frac{1}{2} * L * I_L^2 * \left( \frac{V_{ON(CL)}}{V_{ON(CL)} - V_{bb}} \right), \text{ see diagram page 8}$$

9) Reverse load current (through intrinsic drain-source diode) is normally limited by the connected load. Reverse current  $I_{GND}$  of  $\approx 0.3\text{ A}$  at  $V_{bb} = -32\text{ V}$  through the logic heats up the device. Time allowed under these condition is dependent on the size of the heatsink. Reverse  $I_{GND}$  can be reduced by an additional external GND-resistor ( $150\text{ }\Omega$ ). Input and Status currents have to be limited (see max. ratings page 2 and circuit page 7).

Parameter and Conditions at $T_j = 25^\circ\text{C}$ , $V_{bb} = 12\text{ V}$ unless otherwise specified	Symbol	Values			Unit
		min	typ	max	
<b>Input and Status Feedback<sup>10)</sup></b>					
Input turn-on threshold voltage  $T_j = -40..+150^\circ\text{C}$ :	$V_{IN(T+)}$	1.5	--	2.4	V
Input turn-off threshold voltage  $T_j = -40..+150^\circ\text{C}$ :	$V_{IN(T-)}$	1.0	--	--	V
Input threshold hysteresis	$\Delta V_{IN(T)}$	--	0.5	--	V
Off state input current (pin 2), $V_{IN} = 0.4\text{ V}$	$I_{IN(off)}$	1	--	30	$\mu\text{A}$
On state input current (pin 2), $V_{IN} = 3.5\text{ V}$	$I_{IN(on)}$	10	25	50	$\mu\text{A}$
Status invalid after positive input slope (short circuit) $T_j = -40 \dots +150^\circ\text{C}$ :	$t_{d(ST\ SC)}$	80	200	400	$\mu\text{s}$
Status invalid after positive input slope (open load) $T_j = -40 \dots +150^\circ\text{C}$ :	$t_{d(ST)}$	350	--	1600	$\mu\text{s}$
Status output (CMOS) $T_j = -40\dots+150^\circ\text{C}$ , $I_{ST} = -50\ \mu\text{A}$ :	$V_{ST(high)}^{11)}$	4.4	5.1	6.5	V
$T_j = -40\dots+150^\circ\text{C}$ , $I_{ST} = +1.6\ \text{mA}$ :	$V_{ST(low)}$	--	--	0.4	
Max. status current for current source (out):	$-I_{ST}$	--	--	0.25	mA
valid status output, current sink (in) : $T_j = -40\dots+150^\circ\text{C}$	$+I_{ST}^{12)}$	--	--	1.6	

<sup>10)</sup> If a ground resistor  $R_{GND}$  is used, add the voltage drop across this resistor.

<sup>11)</sup>  $V_{St\ high} \approx V_{bb}$  during undervoltage shutdown

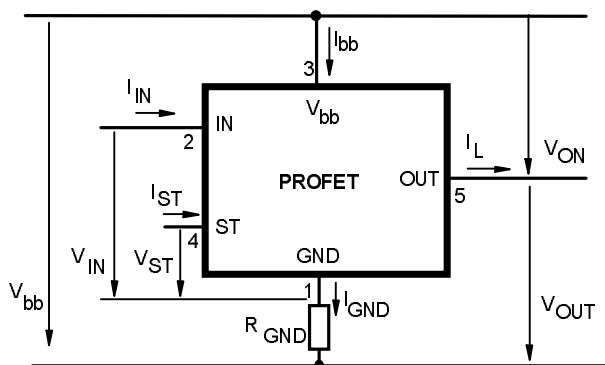
<sup>12)</sup> No current sink capability during undervoltage shutdown

## Truth Table

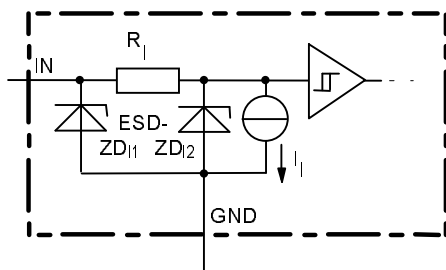
	Input-level	Output level	Status	
			542 D2	542 E2
Normal operation	L	L	H	H
	H	H	H	H
Open load	L	<sup>13)</sup> H	H	H
	H	H	L	L
Short circuit to GND	L	L	H	H
	H	L	L	L
Short circuit to V <sub>bb</sub>	L	H	H	H
	H	H	H (L <sup>14</sup> )	H (L <sup>14</sup> )
Overtemperature	L	L	L	L
	H	L	L	L
Undervoltage	L	L	L <sup>15)</sup>	H
	H	L	L <sup>15)</sup>	H
Overvoltage	L	L	L	H
	H	L	L	H

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

## Terms

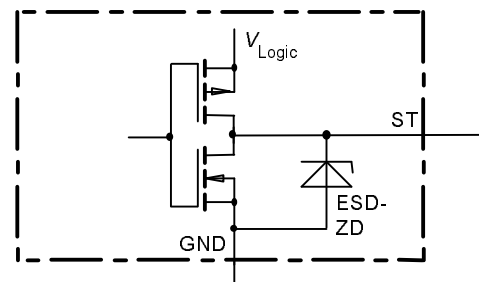


## Input circuit (ESD protection)



ZD<sub>1</sub> 6.1 V typ., 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).

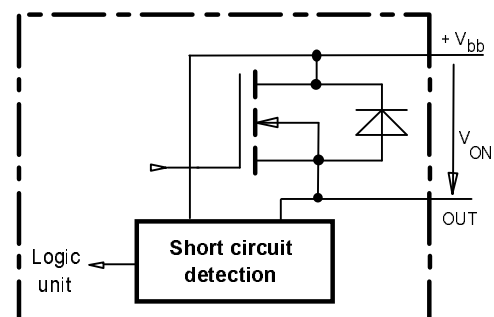
## Status output



Zener diode: 6.1 V typ., max 5 mA, V<sub>Logic</sub> 5 V typ, 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).

## Short Circuit detection

Fault Condition: V<sub>ON</sub> > 8.3 V typ.; IN high

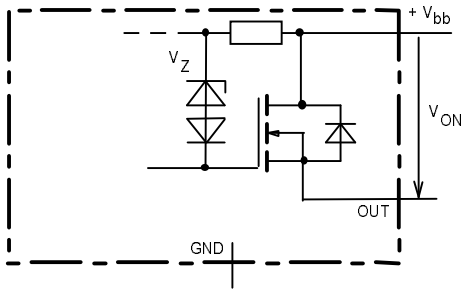


<sup>13)</sup> Power Transistor off, high impedance

<sup>14)</sup> Low resistance short V<sub>bb</sub> to output may be detected by no-load-detection

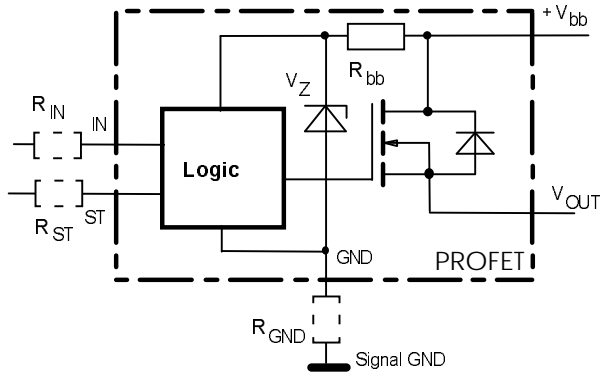
<sup>15)</sup> No current sink capability during undervoltage shutdown

## Inductive and overvoltage output clamp



$V_{ON}$  clamped to 58 V typ.

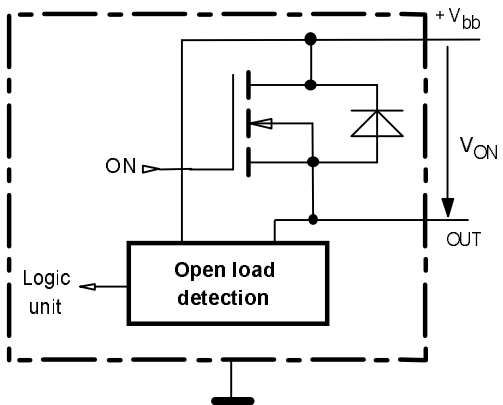
## Overvolt. and reverse batt. protection



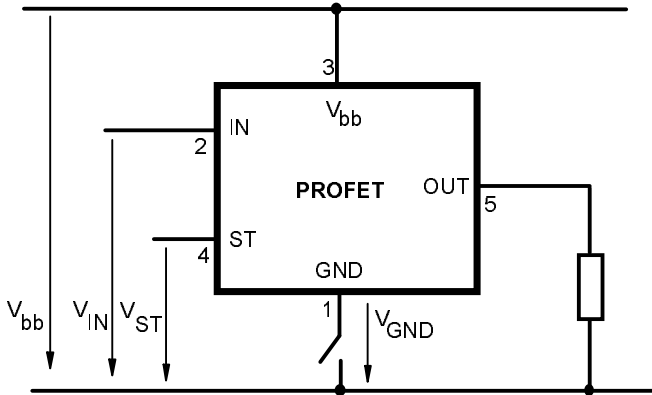
$R_{bb} = 120 \Omega$  typ.,  $V_Z + R_{bb} * 40 \text{ mA} = 67 \text{ V}$  typ., add  $R_{GND}$ ,  $R_{IN}$ ,  $R_{ST}$  for extended protection

## Open-load detection

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

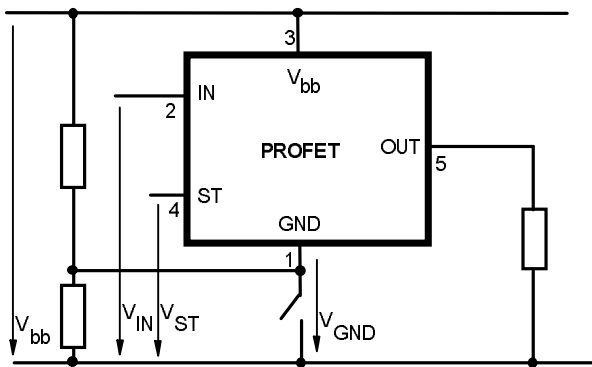


## GND disconnect



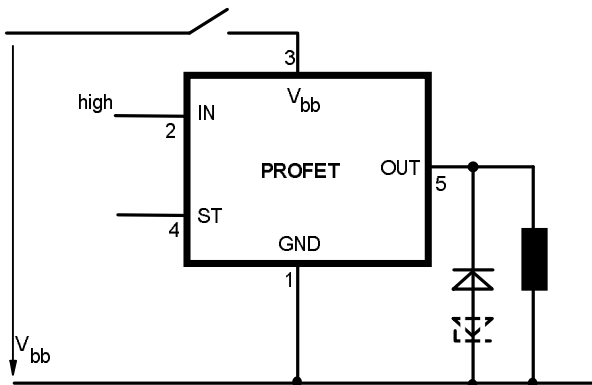
Any kind of load. In case of Input=high is  $V_{OUT} \approx V_{IN} - V_{IN(T+)}$ . Due to  $V_{GND} > 0$ , no  $V_{ST} = \text{low}$  signal available.

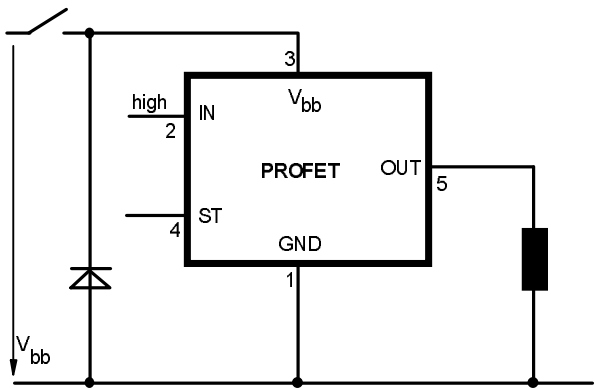
## GND disconnect with GND pull up



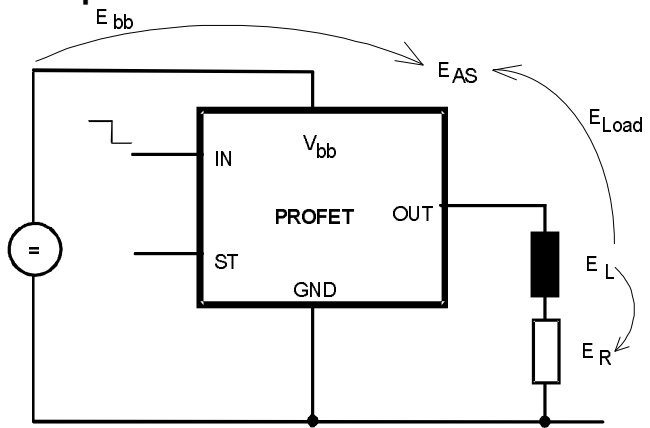
Any kind of load. If  $V_{GND} > V_{IN} - V_{IN(T+)}$  device stays off. Due to  $V_{GND} > 0$ , no  $V_{ST} = \text{low}$  signal available.

## Vbb disconnect with charged inductive load





### Inductive Load switch-off energy dissipation



Energy dissipated in PROFET  $E_{AS} = E_{bb} + E_L - E_R$ .  
 $E_{Load} < E_L$ ,  $E_L = \frac{1}{2} * L * I_L^2$



## Options Overview

**all versions: High-side switch, Input protection, ESD protection, load dump and reverse battery protection , protection against loss of ground**

Type	BTS	542D2	542E2
Logic version		D	E
Overtemperature protection $T_j > 150\text{ °C}$ , latch function <sup>16)17)</sup> $T_j > 150\text{ °C}$ , with auto-restart on cooling		X	X
Short-circuit to GND protection switches off when $V_{ON} > 8.3\text{ V}$ typ. <sup>16)</sup> (when first turned on after approx. 200 $\mu\text{s}$ )		X	X
Open load detection in OFF-state with sensing current 30 $\mu\text{A}$ typ. in ON-state with sensing voltage drop across power transistor		X	X
Undervoltage shutdown with auto restart		X	X
Overvoltage shutdown with auto restart		X	X
Status feedback for			
overtemperature		X	X
short circuit to GND		X	X
short to $V_{bb}$		.18)	.18)
open load		X	X
undervoltage		X	-
overvoltage		X	-
Status output type			
CMOS		X	
Open drain			X
Output negative voltage transient limit (fast inductive load switch off) to $V_{bb} - V_{ON(CL)}$		X	X
Load current limit			
high level (can handle loads with high inrush currents)		X	X
medium level			
low level (better protection of application)			

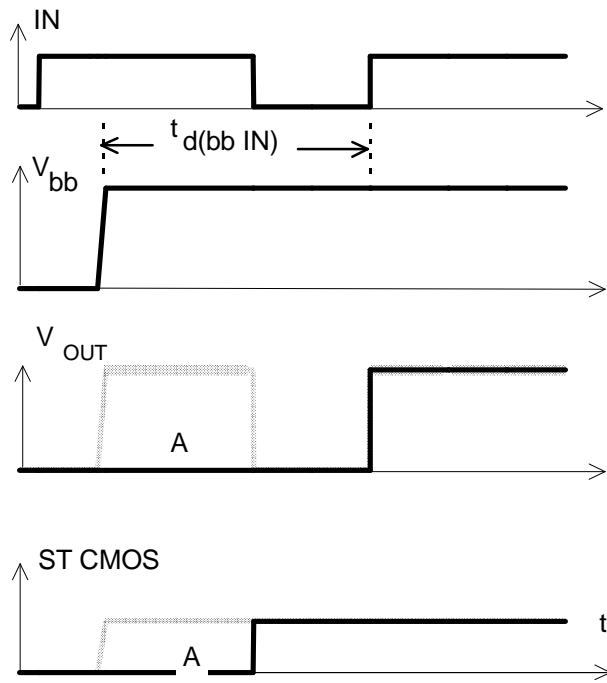
<sup>16)</sup> Latch except when  $V_{bb} - V_{OUT} < V_{ON(SC)}$  after shutdown. In most cases  $V_{OUT} = 0\text{ V}$  after shutdown ( $V_{OUT} \neq 0\text{ V}$  only if forced externally). So the device remains latched unless  $V_{bb} < V_{ON(SC)}$  (see page 4). No latch between turn on and  $t_{d(SC)}$ .

<sup>17)</sup> With latch function. Reseted by a) Input low, b) Undervoltage, c) Overvoltage

<sup>18)</sup> Low resistance short  $V_{bb}$  to output may be detected by no-load-detection

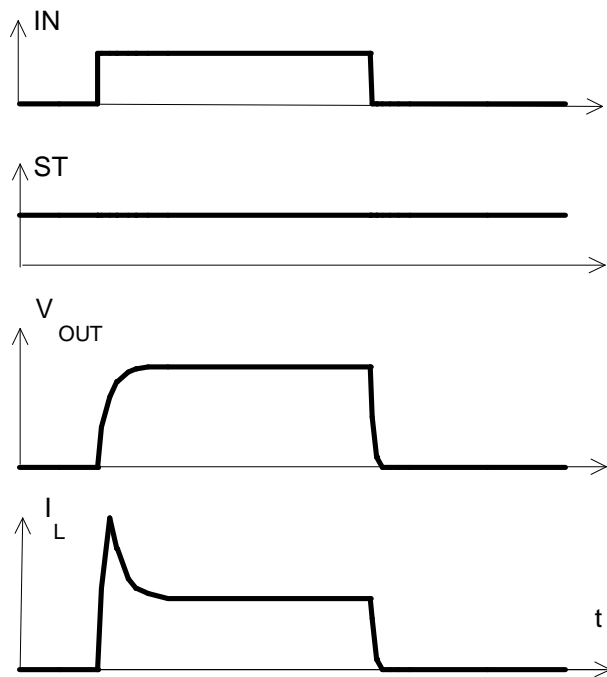
# Timing diagrams

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

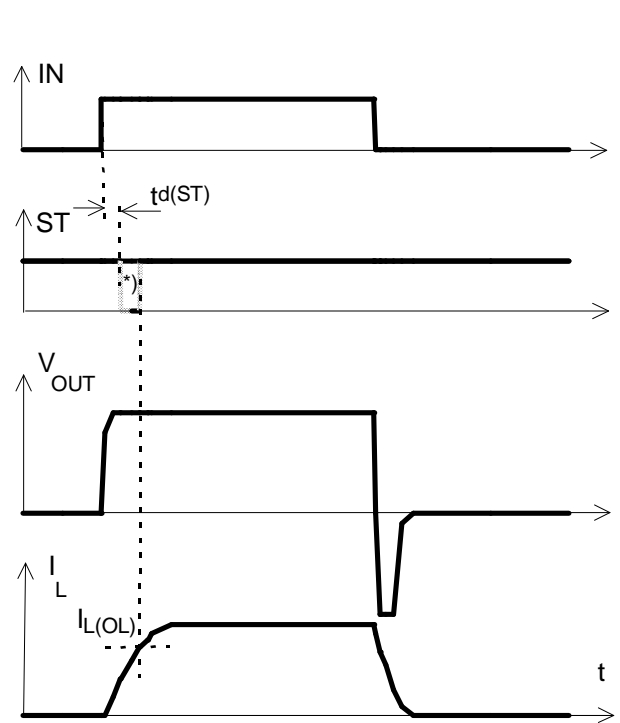


in case of too early  $V_{IN}$ =high the device may not turn on (curve A)  
 $t_{d(bb IN)}$  approx. 150  $\mu$ s

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

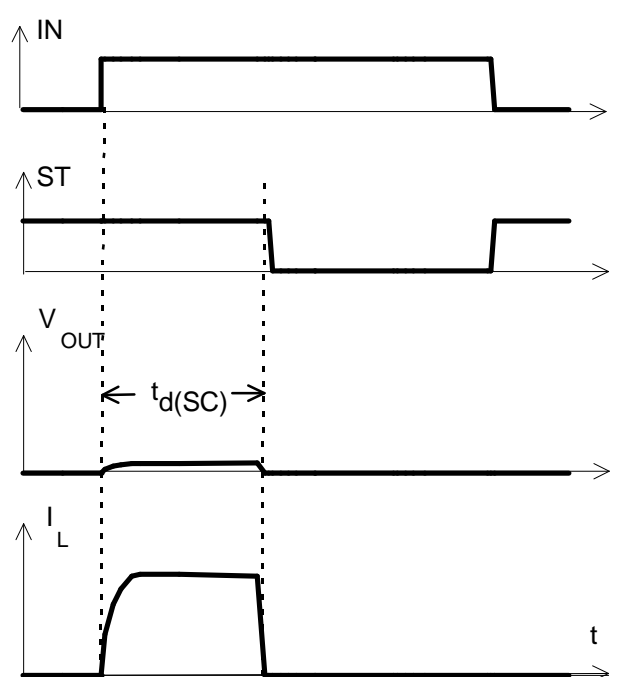


**Figure 2b:** Switching an inductive load



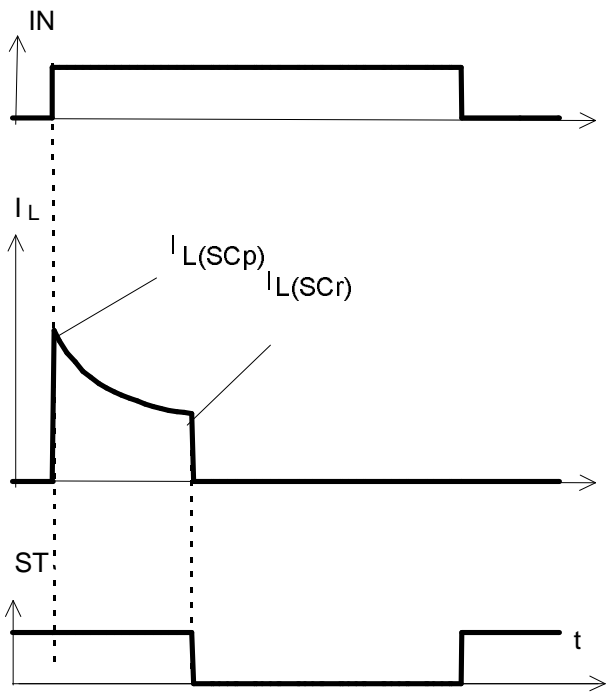
\*) if the time constant of load is too large, open-load-status may occur

**Figure 3a:** Turn on into short circuit,



$t_{d(SC)}$  approx. 200 $\mu$ s if  $V_{bb} - V_{OUT} > 8.3$  V typ.

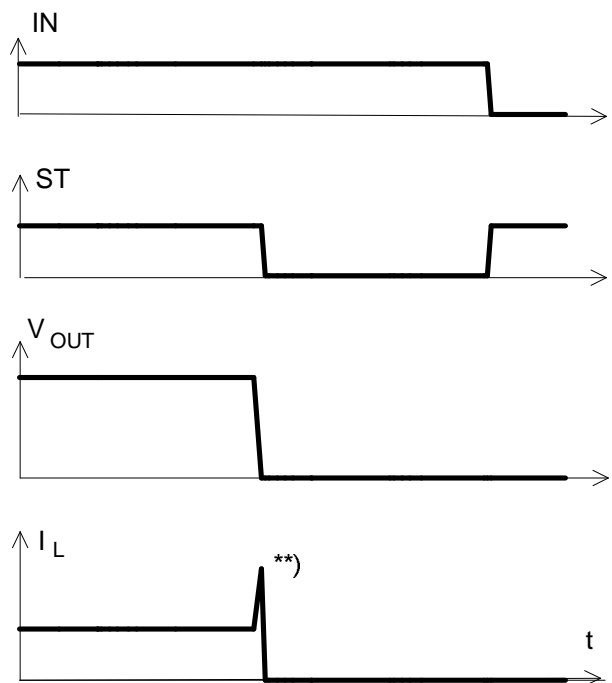
**Figure 3b:** Turn on into overload,



Heating up may require several milliseconds,  
 $V_{bb} - V_{OUT} < 8.3\text{ V typ.}$

$V_{bb} - V_{OUT} < 8.3\text{ V typ.}$

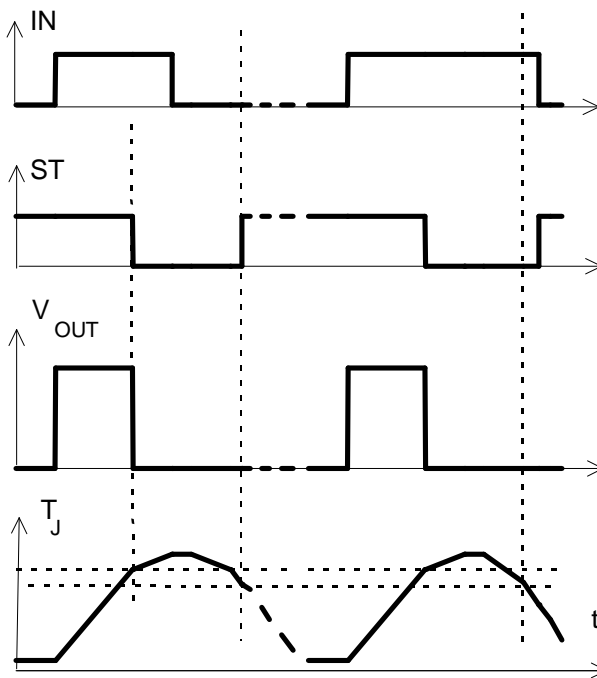
**Figure 3c:** Short circuit while on:



\*\*) current peak approx. 20  $\mu\text{s}$

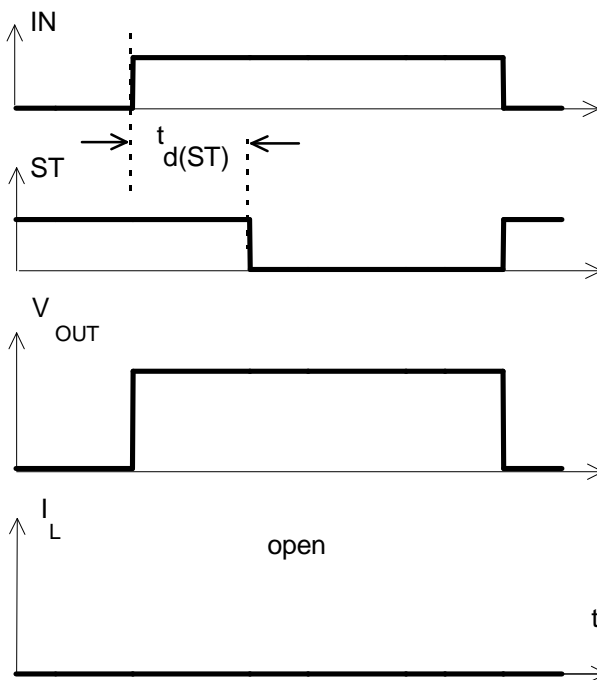
**Figure 4a:** Overtemperature,

Reset if ( $I_N = \text{low}$ ) and ( $T_j < T_{jt}$ )

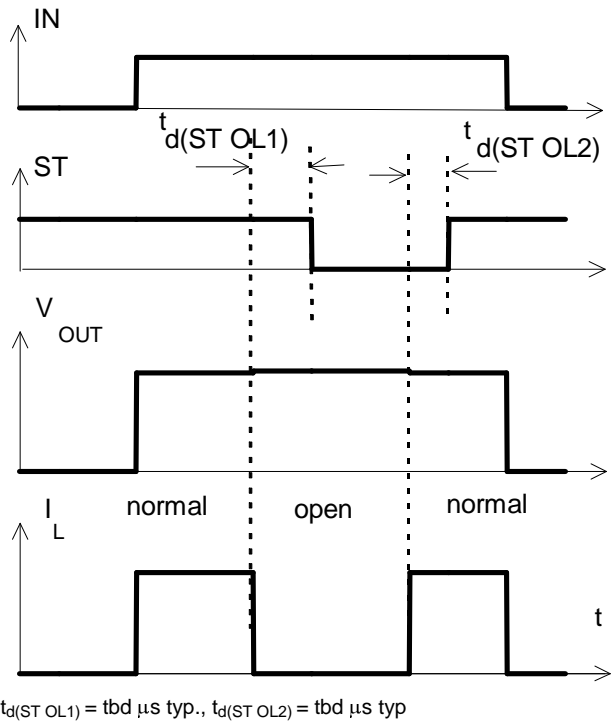


\*) ST goes high, when  $V_{IN} = \text{low}$  and  $T_j < T_{jt}$

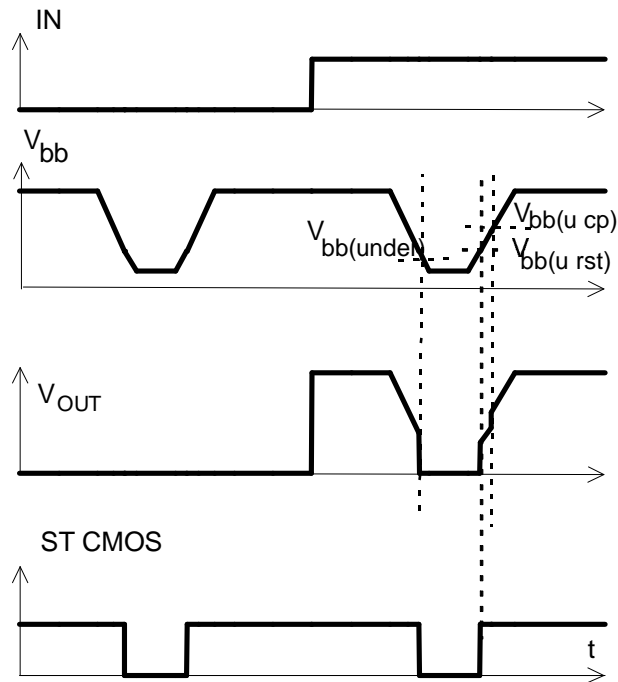
**Figure 5a:** Open load: detection in ON-state, turn on/off to open load



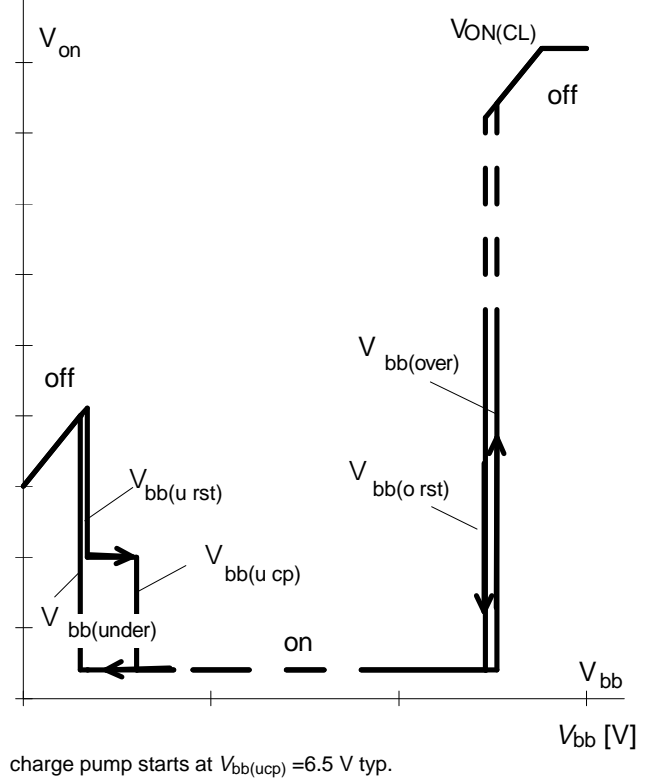
**Figure 5b:** Open load: detection in ON-state, open load occurs in on-state



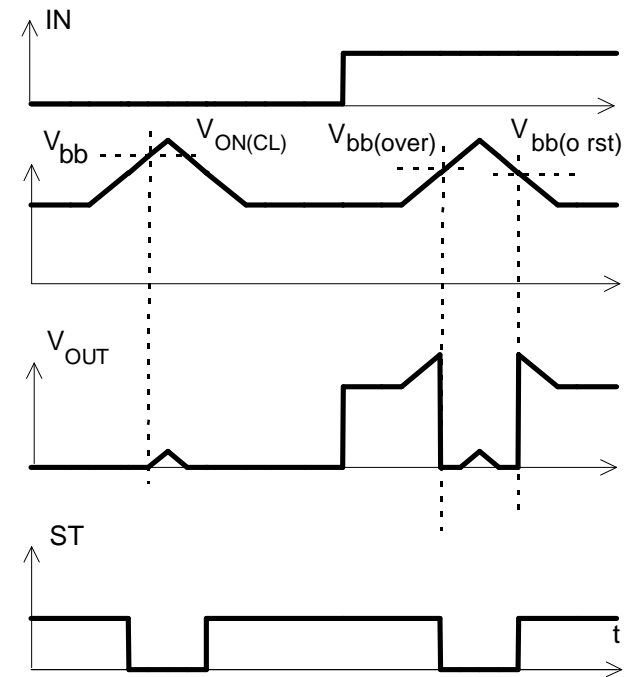
**Figure 6a:** Undervoltage:



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



**Figure 7a:** Overvoltage:



# Package and Ordering Code

All dimensions in mm

**Standard TO-218AB/5**      Ordering code

BTS 542 D2	Q67060-S6950-A2
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