Smart Highside High Current Power Switch

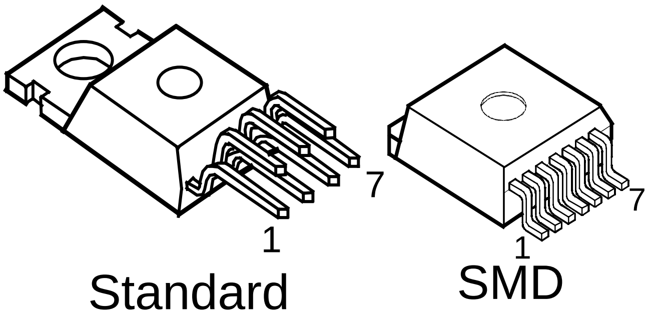
Features

- Overload protection
- Current limitation
- Short circuit protection
- Overtemperature protection
- Overvoltage protection (including load dump)
- Clamp of negative voltage at output
- Fast deenergizing of inductive loads [1]
- Low ohmic inverse current operation
- Reverse battery protection
- Diagnostic feedback with load current sense
- Open load detection via current sense
- Loss of V_{bb} protection[2]
- **E**lectro**s**tatic **d**ischarge (**ESD**) protection

Product Summary

Overvoltage protection	$V_{bb(AZ)}$	62	V
Output clamp	$V_{ON(CL)}$	42	V
Operating voltage	$V_{bb(on)}$	5.0 ... 34	V
On-state resistance	R_{ON}	6.0	mΩ
Load current (ISO)	$I_{L(ISO)}$	70	A
Short circuit current limitation	$I_{L(SC)}$	130	A
Current sense ratio	$I_L : I_{IS}$	14 000	

TO-220AB/7

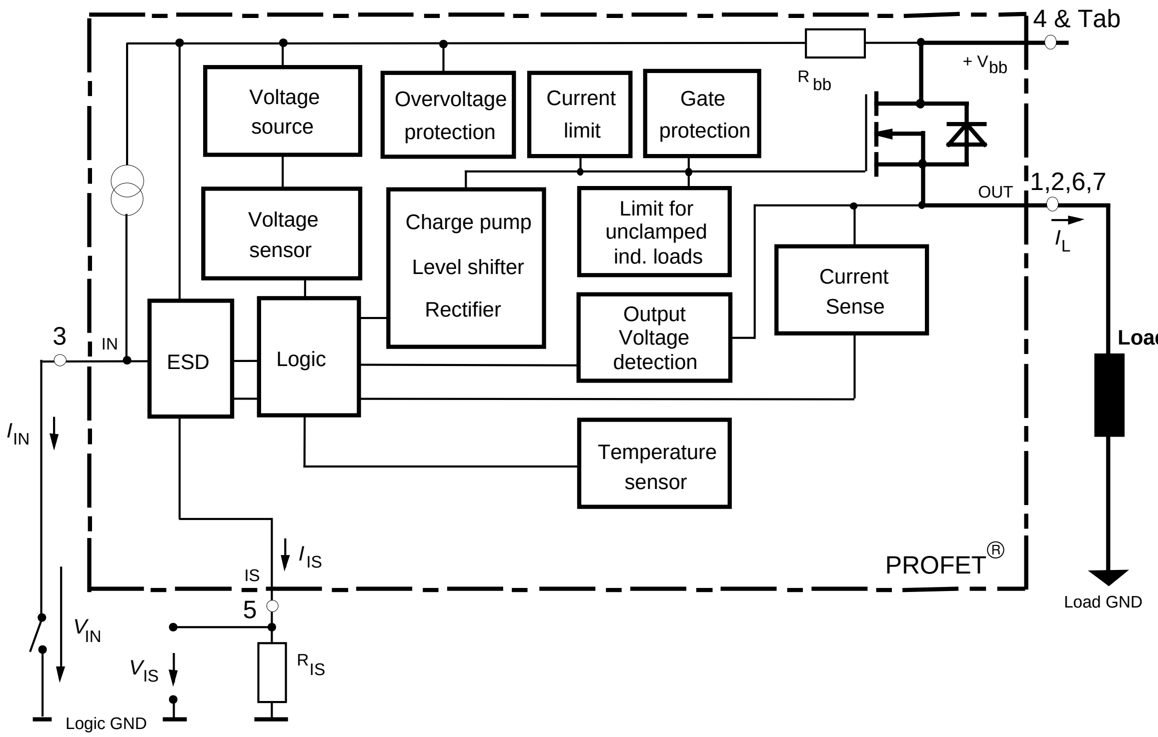


Application

- Power switch with current sense diagnostic feedback for 12 V and 24 V DC grounded loads
- Most suitable for loads with high inrush current like lamps and motors; all types of resistive and inductive loads
- Replaces electromechanical relays, fuses and discrete circuits

General Description

N channel vertical power FET with charge pump, current controlled input and diagnostic feedback with load current sense, integrated in Smart SIPMOS® chip on chip technology. Fully protected by embedded protection functions.



[1]) With additional external diode.
[2]) Additional external diode required for energized inductive loads (see page 9).

Pin	Symbol		Function
1	OUT	O	Output to the load. The pins 1,2,6 and 7 must be shorted with each other especially in high current applications![3)]
2	OUT	O	Output to the load. The pins 1,2,6 and 7 must be shorted with each other especially in high current applications![3)]
3	IN	I	Input, activates the power switch in case of short to ground
4	Vbb	+	Positive power supply voltage, the tab is electrically connected to this pin. In high current applications the tab should be used for the V_{bb} connection instead of this pin[4)].
5	IS	S	Diagnostic feedback providing a sense current proportional to the load current; zero current on failure (see Truth Table on page 7)
6	OUT	O	Output to the load. The pins 1,2,6 and 7 must be shorted with each other especially in high current applications![3)]
7	OUT	O	Output to the load. The pins 1,2,6 and 7 must be shorted with each other especially in high current applications![3)]

Maximum Ratings at T_j = 25 °C unless otherwise specified

Parameter	Symbol	Values	Unit
Supply voltage (overvoltage protection see page 4)	V_{bb}	42	V
Supply voltage for short circuit protection, $T_{j,start}$ =-40 ...+150°C: (see diagram on page 10)	V_{bb}	34	V
Load current (short circuit current, see page 5)	I_L	self-limited	A
Load dump protection $V_{LoadDump} = V_A + V_S$, $V_A = 13.5$ V R_I[5)] = 2 Ω, R_L = 0.54 Ω, t_d = 200 ms, IN, IS = open or grounded	$V_{Load\ dump}$[6)]	75	V
Operating temperature range Storage temperature range	T_j T_{stg}	-40 ...+150 -55 ...+150	°C
Power dissipation (DC), $T_C \leq 25$ °C	P_{tot}	170	W
Inductive load switch-off energy dissipation, single pulse V_{bb} = 12V, $T_{j,start}$ = 150°C, T_C = 150°C const., I_L = 20 A, Z_L = 7.5 mH, 0 Ω, see diagrams on page 10	E_{AS}	1.5	J
Electrostatic discharge capability (ESD) Human Body Model acc. MIL-STD883D, method 3015.7 and ESD assn. std. S5.1-1993, C = 100 pF, R = 1.5 kΩ	V_{ESD}	4	kV
Current through input pin (DC) Current through current sense status pin (DC) see internal circuit diagrams on page 7 and 8	I_{IN} I_{IS}	+15 , -250 +15 , -250	mA

3) Not shorting all outputs will considerably increase the on-state resistance, reduce the peak current capability and decrease the current sense accuracy

4) Otherwise add up to 0.7 mΩ (depending on used length of the pin) to the R_{ON} if the pin is used instead of the tab.

5) R_I = internal resistance of the load dump test pulse generator.

6) $V_{Load\ dump}$ 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:	R_{thJC} 7)	--	--	0.75	K/W
junction - ambient (free air):	R_{thJA}	--	60	--	
SMD version, device on PCB 8):			33		

Electrical Characteristics

Parameter and Conditions	Symbol	Values			Unit
at T_j = -40 ... +150 °C, V_{bb} = 12 V unless otherwise specified		min	typ	max	

Load Switching Capabilities and Characteristics

On-state resistance (Tab to pins 1,2,6,7, see measurement circuit page 7) I_L = 20 A, T_j = 25 °C:	R_{ON}	--	4.4	6.0	mΩ
V_{IN} = 0, I_L = 20 A, T_j = 150 °C:			7.9	10.5	
I_L = 90 A, T_j = 150 °C:			--	10.7	
V_{bb} = 6V 9), I_L = 20 A, T_j = 150 °C:	$R_{ON(Static)}$	--	10	17	
Nominal load current 10) (Tab to pins 1,2,6,7) ISO 10483-1/6.7: V_{ON} = 0.5 V, T_C = 85 °C 11)	$I_{L(ISO)}$	55	70	--	A
Nominal load current 10), device on PCB 8)) T_A = 85 °C, $T_j \leq$ 150 °C $V_{ON} \leq$ 0.5 V,	$I_{L(NOM)}$	13.6	17	--	A
Maximum load current in resistive range (Tab to pins 1,2,6,7) V_{ON} = 1.8 V, T_C = 25 °C:	$I_{L(Max)}$	250	--	--	
see diagram on page 13 V_{ON} = 1.8 V, T_C = 150 °C:		150	--	--	A
Turn-on time 12) I_{IN} _⌐‾ to 90% V_{OUT}:	t_{on}	100	--	420	µs
Turn-off time I_{IN} ‾¬_ to 10% V_{OUT}: R_L = 1 Ω, T_j = -40...+150°C	t_{off}	30	--	110	
Slew rate on 12) (10 to 30% V_{OUT}) R_L = 1 Ω, T_J = 25 °C	dV/dt$_{on}$	--	0.7	--	V/µs
Slew rate off 12) (70 to 40% V_{OUT}) R_L = 1 Ω, T_J = 25 °C	-dV/dt$_{off}$	--	1.1	--	V/µs

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7) Thermal resistance R_{thCH} case to heatsink (about 0.5 ... 0.9 K/W with silicone paste) not included!

8) Device on 50mm*50mm*1.5mm epoxy PCB FR4 with 6cm^2 (one layer, 70µm thick) copper area for V_{bb} connection. PCB is vertical without blown air.

9) Decrease of V_{bb} below 10 V causes slowly a dynamic increase of R_{ON} to a higher value of $R_{ON(Static)}$. As long as $V_{bIN} > V_{bIN(u)\,max}$, R_{ON} increase is less than 10 % per second for T_J < 85 °C.

10) Not tested, specified by design.

11) T_J is about 105°C under these conditions.

12) See timing diagram on page 14.

Inverse Load Current Operation

On-state resistance (Pins 1,2,6,7 to pin 4) V_{bIN} = 12 V, I_L = - 20 A, T_j = 25 °C: see diagram on page 10, T_j = 150 °C:	$R_{ON(inv)}$	--	4.4 7.9	6.0 10.5	mΩ
Nominal inverse load current (Pins 1,2,6,7 to Tab) V_{ON} = -0.5 V, T_C = 85 °C[11]	$I_{L(inv)}$	55	70	--	A
Drain-source diode voltage (V_{out} > V_{bb}) I_L = - 20 A, I_{IN} = 0, T_j = +150°C	-V_{ON}	--	0.6	--	V

Operating Parameters

Operating voltage (V_{IN} = 0) [9, 13]	$V_{bb(on)}$	5.0	--	34	V
Undervoltage shutdown [14]	$V_{bIN(u)}$	1.5	3.0	4.5	V
Undervoltage start of charge pump see diagram page 15	$V_{bIN(ucp)}$	3.0	4.5	6.0	V
Overvoltage protection[15], T_j = -40°C: I_{bb} = 15 mA, T_j = 25...+150°C:	$V_{bIN(Z)}$	60 62	-- 66	-- --	V
Standby current, T_j = -40...+25°C: I_{IN} = 0, T_j = 150°C:	$I_{bb(off)}$	-- --	15 25	25 50	µA

13) If the device is turned on before a V_{bb}-decrease, the operating voltage range is extended down to $V_{bIN(u)}$. For all voltages 0 ... 34 V the device is fully protected against overtemperature and short circuit.

14) $V_{bIN} = V_{bb} - V_{IN}$ see diagram on page 7. When V_{bIN} increases from less than $V_{bIN(u)}$ up to $V_{bIN(ucp)}$ = 5 V (typ.) the charge pump is not active and $V_{OUT} \approx V_{bb}$ - 3 V.

15) See also $V_{ON(CL)}$ in circuit diagram on page 9.

Parameter and Conditions at T_j = -40 ... +150 °C, V_{bb} = 12 V unless otherwise specified	Symbol	Values min	Values typ	Values max	Unit
Protection Functions					
Short circuit current limit (Tab to pins 1,2,6,7) V_{ON} = 12 V, time until shutdown max. 350 µs T_c =-40°C:	$I_{L(SC)}$	--	110	--	A
T_c =25°C:	$I_{L(SC)}$	--	130	180	
T_c =+150°C:	$I_{L(SC)}$	65	115	--	
Short circuit shutdown delay after input current positive slope, V_{ON} > $V_{ON(SC)}$ min. value valid only if input "off-signal" time exceeds 30 µs	$t_{d(SC)}$	80	--	350	µs
Output clamp [16] I_L= 40 mA: (inductive load switch off) see diagram Ind. and overvolt. output clamp page 8	$-V_{OUT(CL)}$	14	16.5	20	V
Output clamp (inductive load switch off) at V_{OUT} = V_{bb} - $V_{ON(CL)}$ (e.g. overvoltage) I_L= 40 mA	$V_{ON(CL)}$	39	42	47	V
Short circuit shutdown detection voltage (pin 4 to pins 1,2,6,7)	$V_{ON(SC)}$	--	6	--	V
Thermal overload trip temperature	T_{jt}	150	--	--	°C
Thermal hysteresis	ΔT_{jt}	--	10	--	K

Reverse Battery

Reverse battery voltage [17]	$-V_{bb}$	--	--	32	V
On-state resistance (Pins 1,2,6,7 to pin 4) T_j = 25 °C: V_{bb}=-12V, V_{IN}=0, I_L=-20 A, R_{IS}=1 kΩ T_j = 150 °C:	$R_{ON(rev)}$	--	5.4 8.9	7.0 12.3	mΩ
Integrated resistor in V_{bb} line	R_{bb}	--	120	--	Ω

[16] This output clamp can be "switched off" by using an additional diode at the IS-Pin (see page 8). If the diode is used, V_{OUT} is clamped to V_{bb}- $V_{ON(CL)}$ at inductive load switch off.

[17] The reverse load current through the intrinsic drain-source diode has to be limited by the connected load (as it is done with all polarity symmetric loads). Note that under off-conditions (I_{IN} = I_{IS} = 0) the power transistor is not activated. This results in raised power dissipation due to the higher voltage drop across the intrinsic drain-source diode. The temperature protection is not active during reverse current operation! Increasing reverse battery voltage capability is simply possible as described on page 9.

Parameter and Conditions at T_j = -40 ... +150 °C, V_{bb} = 12 V unless otherwise specified	Symbol	Values min	Values typ	Values max	Unit

Diagnostic Characteristics

Parameter and Conditions		Symbol	min	typ	max	Unit
Current sense ratio,	I_L = 90 A, T_j =-40°C:	k_{ILIS}	12 500	14 200	16 000	
static on-condition,	T_j =25°C:		12 500	13 700	16 000	
$k_{ILIS} = I_L : I_{IS}$,	T_j =150°C:		11 500	13 000	14 500	
$V_{ON} < 1.5\,V$[18],	I_L = 20 A, T_j =-40°C:		12 500	14 500	17 500	
$V_{IS} < V_{OUT}$ - 5V,	T_j =25°C:		12 000	14 000	16 500	
$V_{bIN} > 4.0\,V$	T_j =150°C:		11 500	13 400	15 000	
see diagram on page 12	I_L = 10 A, T_j =-40°C:		12 500	15 000	19 000	
	T_j =25°C:		11 500	14 300	17 500	
	T_j =150°C:		11 500	13 500	15 500	
	I_L = 4 A, T_j =-40°C:		11 000	18 000	28 500	
	T_j =25°C:		11 000	15 400	22 000	
	T_j =150°C:		11 200	14 000	19 000	
I_{IS}=0 by I_{IN} =0 (e.g. during deenergizing of inductive loads):						
Sense current saturation		$I_{IS,lim}$	6.5	--	--	mA
Current sense leakage current	I_{IN} = 0:	$I_{IS(LL)}$	--	--	0.5	µA
	V_{IN} = 0, $I_L \leq 0$:	$I_{IS(LH)}$	--	2	--	
Current sense overvoltage protection	T_j =-40°C:	$V_{bIS(Z)}$	60	--	--	V
I_{bb} = 15 mA	T_j = 25...+150°C:		62	66	--	
Current sense settling time[19]		$t_{s(IS)}$	--	--	500	µs

Input

Parameter and Conditions	Symbol	min	typ	max	Unit
Input and operating current (see diagram page 13) IN grounded (V_{IN} = 0)	$I_{IN(on)}$	--	0.8	1.5	mA
Input current for turn-off[20]	$I_{IN(off)}$	--	--	80	µA

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18) If V_{ON} is higher, the sense current is no longer proportional to the load current due to sense current saturation, see $I_{IS,lim}$.

19) Not tested, specified by design.

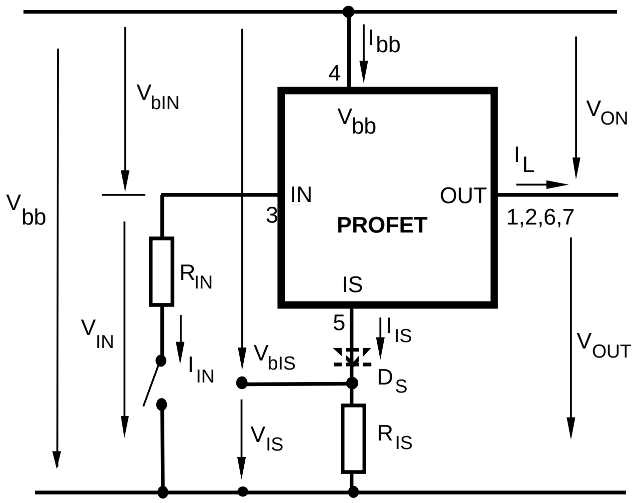
20) We recommend the resistance between IN and GND to be less than 0.5 kΩ for turn-on and more than 500kΩ for turn-off. Consider that when the device is switched off (I_{IN} = 0) the voltage between IN and GND reaches almost V_{bb}.

Truth Table

	Input current level	Output level	Current Sense I_{IS}	Remark
Normal operation	L H	L H	0 nominal	$=I_L / k_{ilis}$, up to $I_{IS}=I_{IS,lim}$
Very high load current	H	H	$I_{IS, lim}$	up to $V_{ON}=V_{ON(Fold\ back)}$ I_{IS} no longer proportional to I_L
Current-limitation	H	H	0	$V_{ON} > V_{ON(Fold\ back)}$ if $V_{ON}>V_{ON(SC)}$, shutdown will occure
Short circuit to GND	L H	L L	0 0	
Over-temperature	L H	L L	0 0	
Short circuit to V_{bb}	L H	H H	0 <nominal [21]	
Open load	L H	Z[22] H	0 0	
Negative output voltage clamp	L	L	0	
Inverse load current	L H	H H	0 0	

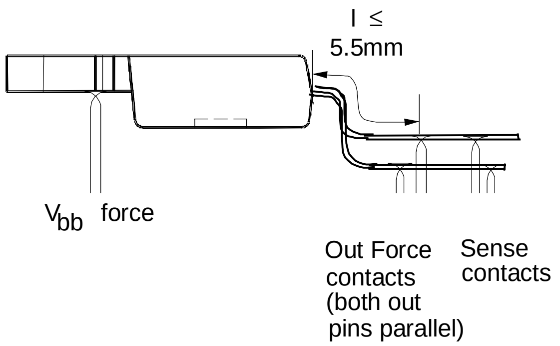
L = "Low" Level
H = "High" Level
Overtemperature reset by cooling: $T_j < T_{jt}$ (see diagram on page 15)
Short circuit to GND: Shutdown remains latched until next reset via input (see diagram on page 14)

Terms



Two or more devices can easily be connected in parallel to increase load current capability.

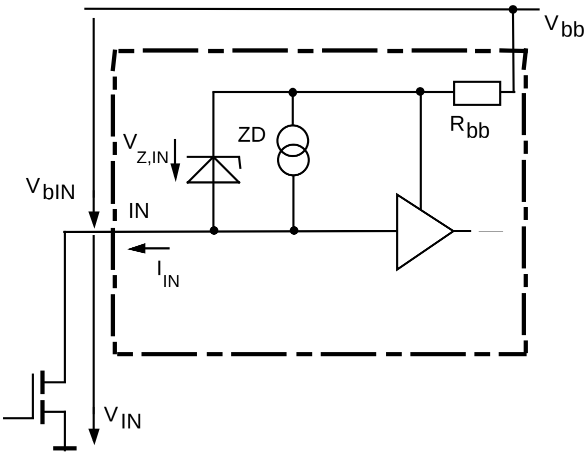
R_{ON} measurement layout



Typical R_{ON} for SMD version is about 0.2 mΩ less than straight leads due to l ≈ 2 mm

[21]) Low ohmic short to V_{bb} may reduce the output current I_L and can thus be detected via the sense current I_{IS}.
[22]) Power Transistor "OFF", potential defined by external impedance.

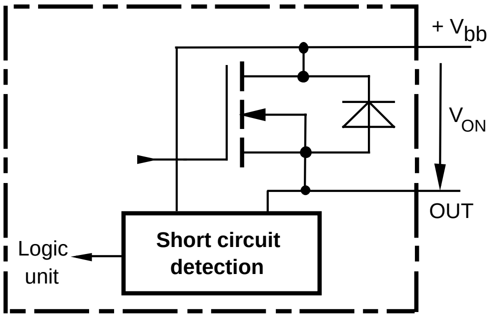
Input circuit (ESD protection)



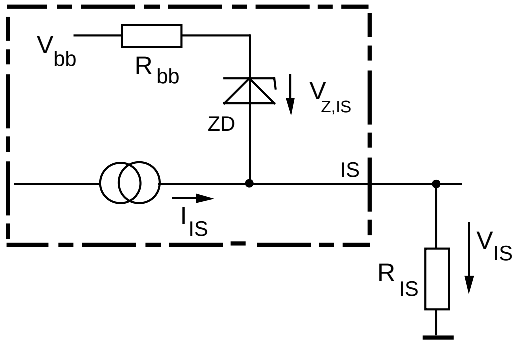
When the device is switched off ($I_{IN} = 0$) the voltage between IN and GND reaches almost V_{bb}. Use a mechanical switch, a bipolar or MOS transistor with appropriate breakdown voltage as driver.
$V_{Z,IN} = 66\,V$ (typ).

Short circuit detection

Fault Condition: $V_{ON} > V_{ON(SC)}$ (6 V typ.) and t> $t_{d(SC)}$ (80 ...350 µs).

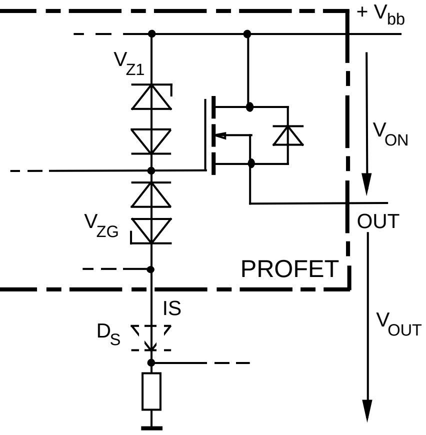


Current sense status output



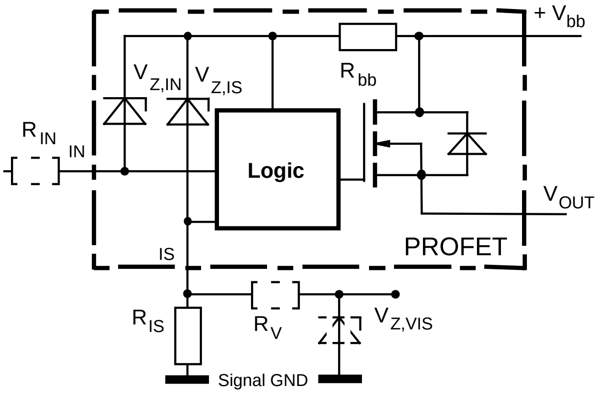
$V_{Z,IS} = 66\,V$ (typ.), $R_{IS} = 1\,k\Omega$ nominal (or $1\,k\Omega$ /n, if n devices are connected in parallel). $I_S = I_L / k_{ilis}$ can be driven only by the internal circuit as long as $V_{out} - V_{IS} >$ 5 V. If you want measure load currents up to $I_{L(M)}$, R_{IS} should be less than $\frac{V_{bb} - 5\,V}{I_{L(M)} / K_{ilis}}$.
Note: For large values of R_{IS} the voltage V_{IS} can reach almost V_{bb}. See also overvoltage protection.
If you don't use the current sense output in your application, you can leave it open.

Inductive and overvoltage output clamp



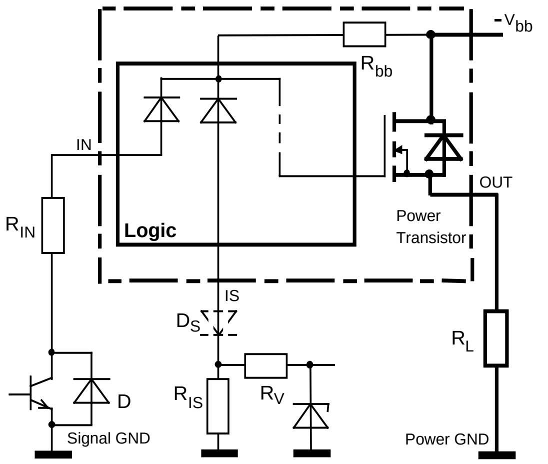
V_{ON} is clamped to $V_{ON(Cl)} = 42\,V$ typ. At inductive load switch-off without D_S, V_{OUT} is clamped to $V_{OUT(CL)} =$ -19 V typ. via V_{ZG}. With D_S, V_{OUT} is clamped to $V_{bb} - V_{ON(CL)}$ via V_{Z1}. Using D_S gives faster deenergizing of the inductive load, but higher peak power dissipation in the PROFET.

Overvoltage protection of logic part



$R_{bb} = 120\,\Omega$ typ., $V_{Z,IN} = V_{Z,IS} = 66\,V$ typ., $R_{IS} = 1\,k\Omega$ nominal. Note that when overvoltage exceeds 71 V typ. a voltage above 5V can occur between IS and GND, if R_V, $V_{Z,VIS}$ are not used.

Reverse battery protection



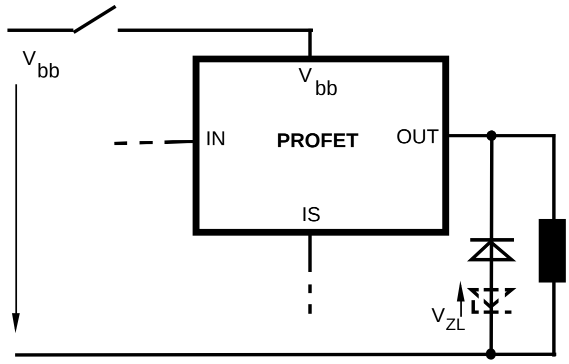
$R_V \geq 1\,k\Omega$, $R_{IS} = 1\,k\Omega$ nominal. Add R_{IN} for reverse battery protection in applications with V_{bb} above 16 V[17]; recommended value: $\frac{1}{R_{IN}} + \frac{1}{R_{IS}} + \frac{1}{R_V} = \frac{0.1A}{|V_{bb}| - 12V}$ if D_S is not used (or $\frac{1}{R_{IN}} = \frac{0.1A}{|V_{bb}| - 12V}$ if D_S is used).

To minimize power dissipation at reverse battery operation, the summarized current into the IN and IS pin should be about 120mA. The current can be provided by using a small signal diode D in parallel to the input switch, by using a MOSFET input switch or by proper adjusting the current through R_{IS} and R_V.

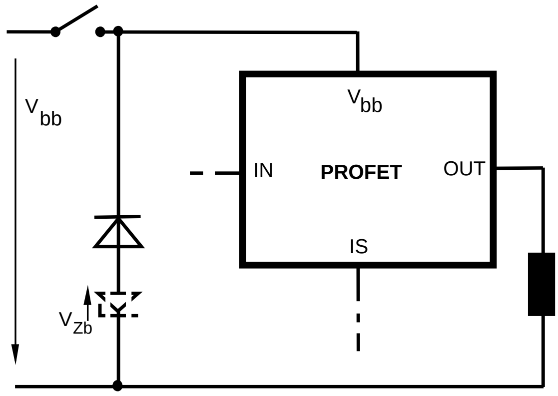
V_{bb} disconnect with energized inductive load

Provide a current path with load current capability by using a diode, a Z-diode, or a varistor. ($V_{ZL} < 72$ V or $V_{Zb} < 30$ V if R_{IN}=0). For higher clamp voltages currents at IN and IS have to be limited to 250 mA.

Version a:

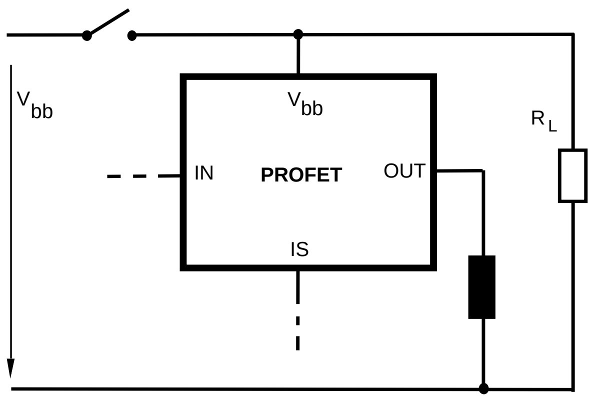


Version b:

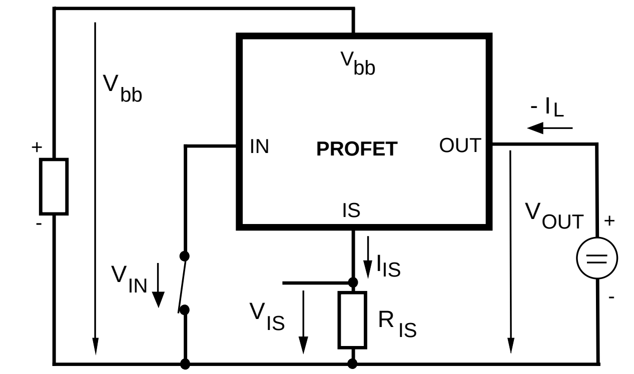


Note that there is no reverse battery protection when using a diode without additional Z-diode V_{ZL}, V_{Zb}.

Version c: Sometimes a neccessary voltage clamp is given by non inductive loads R_L connected to the same switch and eliminates the need of clamping circuit:

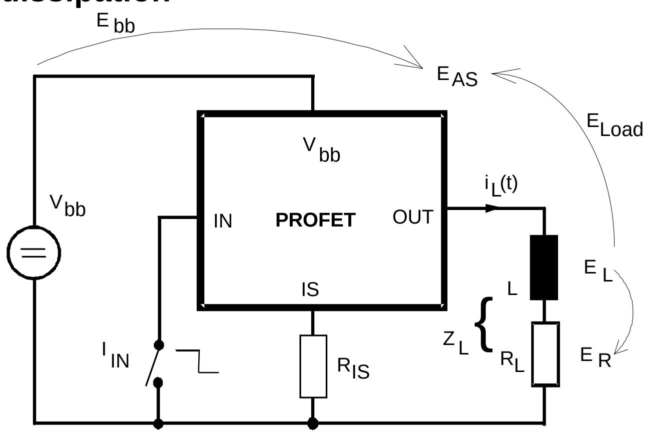


Inverse load current operation



The device is specified for inverse load current operation ($V_{OUT} > V_{bb}$ **> 0V**). The current sense feature is not available during this kind of operation (I_{IS} = 0). With I_{IN} = 0 (e.g. input open) only the intrinsic drain source diode is conducting resulting in considerably increased power dissipation. If the device is switched on (V_{IN} = 0), this power dissipation is decreased to the much lower value $R_{ON(INV)} * I^2$ (specifications see page 4).
Note: *Temperature protection during inverse load current operation is not possible!*

Inductive load switch-off energy dissipation



Energy stored in load inductance:

$$E_L = {}^1/_2 \cdot L \cdot I_L^2$$

While demagnetizing load inductance, the energy dissipated in PROFET is

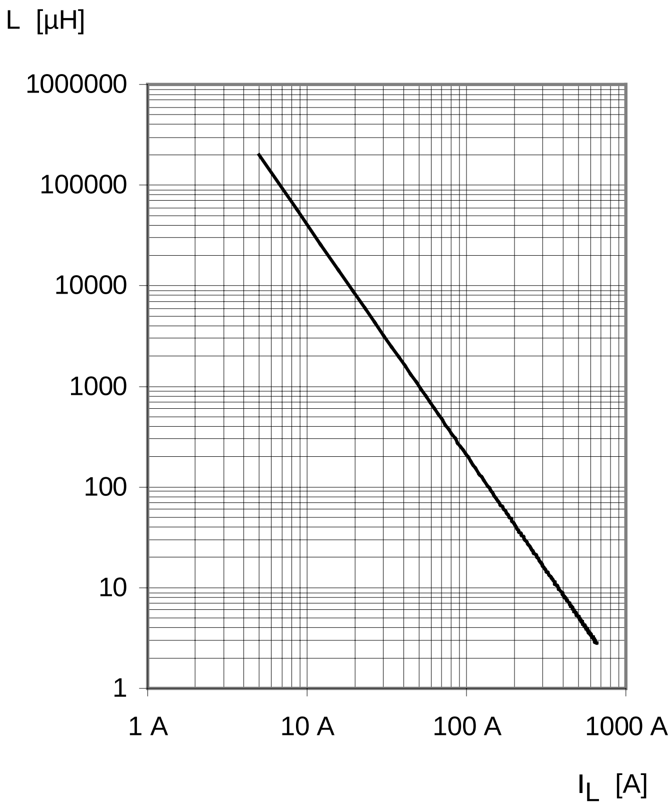
$$E_{AS} = E_{bb} + E_L - E_R = \int V_{ON(CL)} \cdot i_L(t)\, dt,$$

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

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

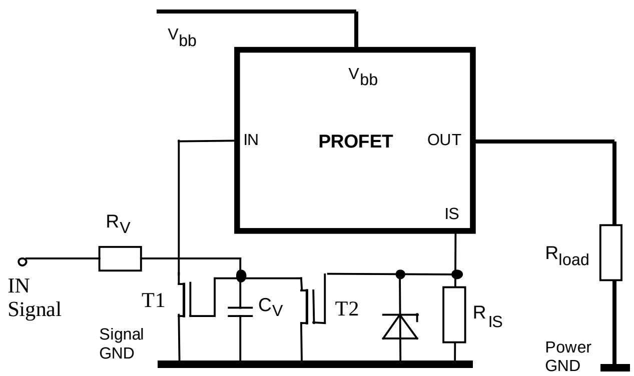
Maximum allowable load inductance for a single switch off

$L = f(I_L)$; $T_{j,start} = 150°C$, $V_{bb} = 12\,V$, $R_L = 0\,\Omega$



Externally adjustable current limit

If the device is conducting, the sense current can be used to reduce the short circuit current and allow higher lead inductance (see diagram above). The device will be turned off, if the threshold voltage of T2 is reached by $I_s * R_{IS}$. After a delay time defined by $R_V * C_V$ T1 will be reset. The device is turned on again, the short circuit current is defined by $I_{L(SC)}$ and the device is shut down after $t_{d(SC)}$ with latch function.



Options Overview

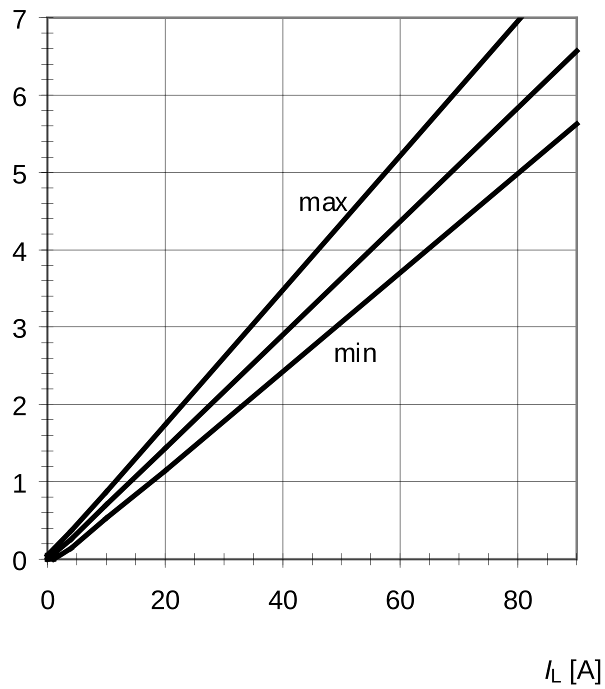
Type BTS	550P 650P	555
Overtemperature protection with hysteresis	X	X
T_j >150 °C, latch function[23]		X
T_j >150 °C, with auto-restart on cooling	X	
Short circuit to GND protection		
switches off when V_{ON}>6 V typ. (when first turned on after approx. 180 µs)	X	X
Overvoltage shutdown	-	-
Output negative voltage transient limit		
to V_{bb} - $V_{ON(CL)}$	X	X
to V_{OUT} = -19 V typ	X[24]	X[24]

[23] Latch except when V_{bb} -V_{OUT} < $V_{ON(SC)}$ after shutdown. In most cases V_{OUT} = 0 V after shutdown (V_{OUT} ≠ 0 V only if forced externally). So the device remains latched unless V_{bb} < $V_{ON(SC)}$ (see page 5). No latch between turn on and $t_{d(SC)}$.

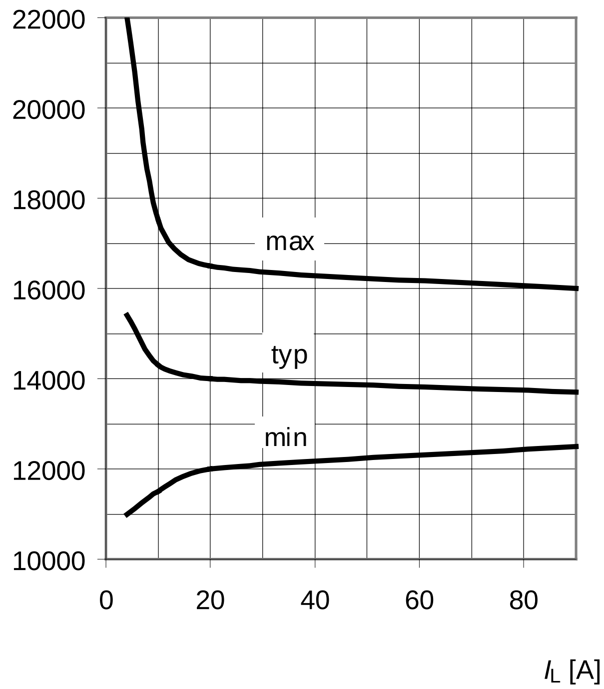
[24] Can be "switched off" by using a diode D_S (see page 8) or leaving open the current sense output.

Characteristics

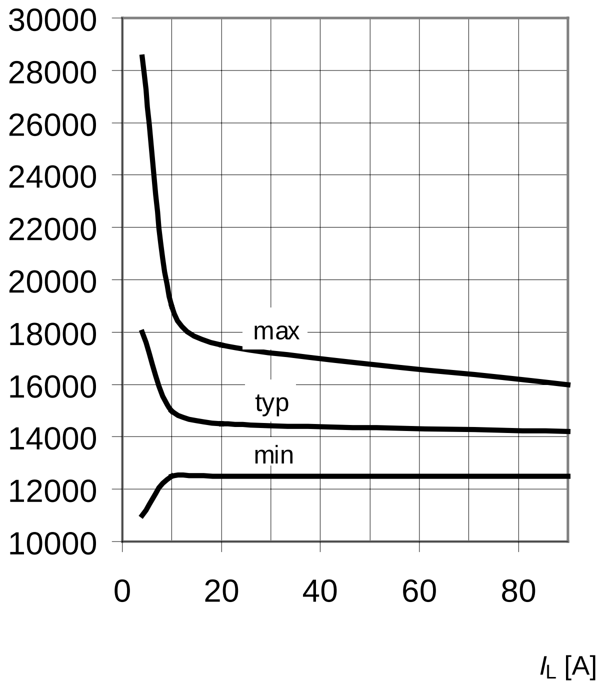
Current sense versus load current:
$I_{IS} = f(I_L)$, T_J= -40 ... +150 °C
I_{IS} [mA]



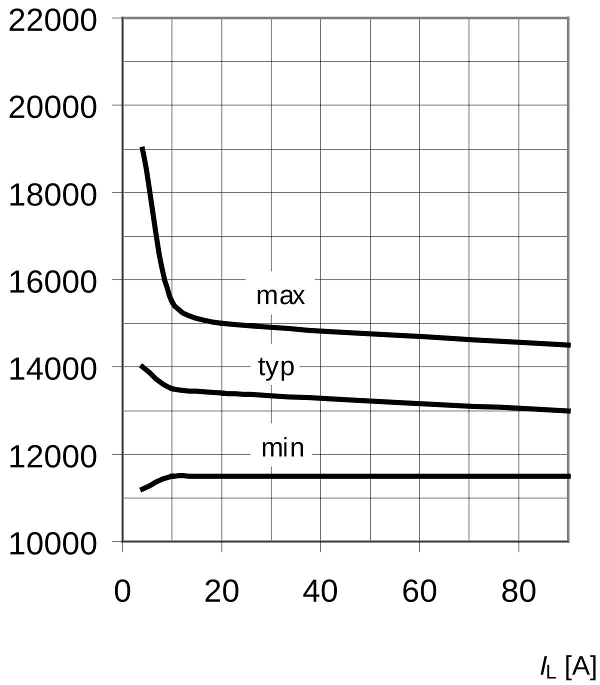
Current sense ratio:
$I_{IS} = f(I_L)$, T_J= 25 °C
k_{ILIS}



Current sense ratio:
$K_{ILIS} = f(I_L)$, T_J = -40°C
k_{ilis}

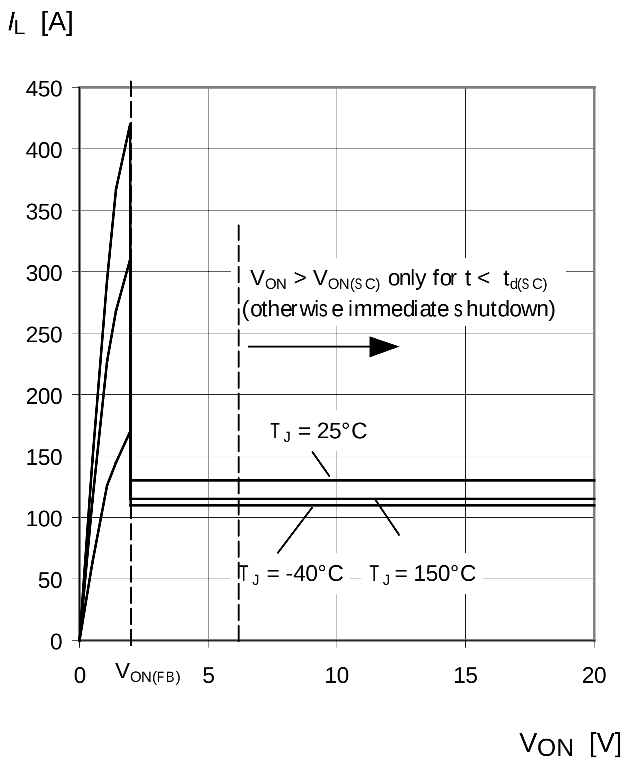


Current sense ratio:
$K_{ILIS} = f(I_L)$, T_J = 150°C
k_{ilis}



Typ. current limitation characteristic

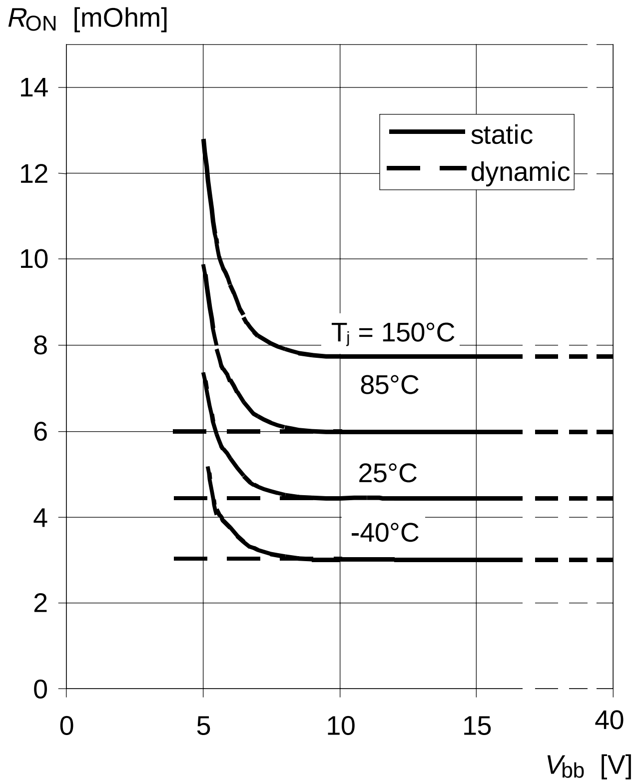
$I_L = f(V_{ON}, T_j)$



In case of $V_{ON} > V_{ON(SC)}$ (typ. 6 V) the device will be switched off by internal short circuit detection.

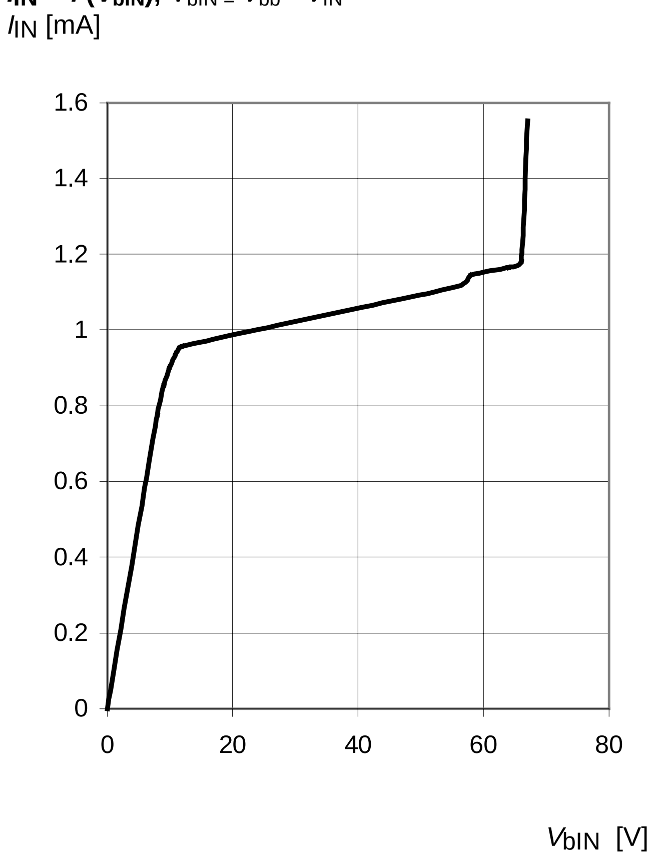
Typ. on-state resistance

$R_{ON} = f(V_{bb}, T_j)$; I_L = 20 A; V_{IN} = 0



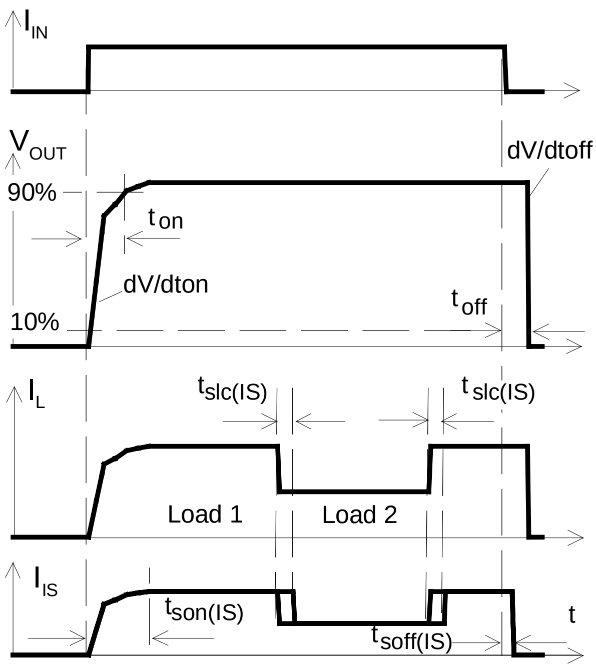
Typ. input current

$I_{IN} = f(V_{bIN})$, $V_{bIN} = V_{bb} - V_{IN}$



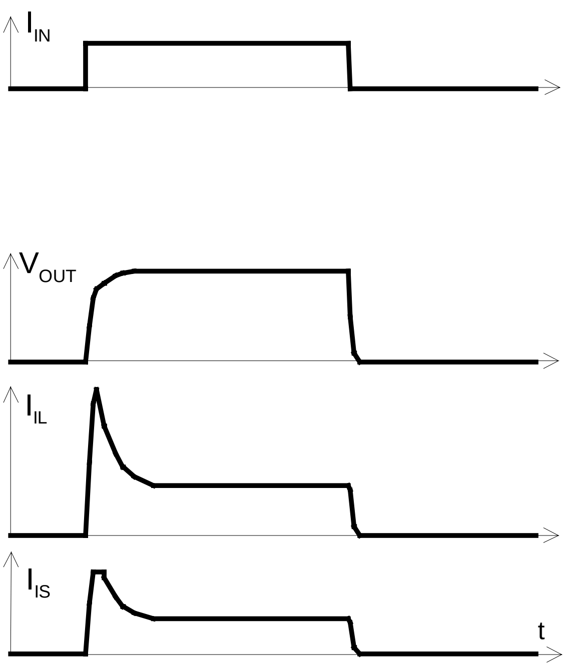
Timing diagrams

Figure 1a: Switching a resistive load, change of load current in on-condition:



The sense signal is not valid during a settling time after turn-on/off and after change of load current.

Figure 2a: Switching motors and lamps:



Sense current saturation can occur at very high inrush currents (see $I_{IS,lim}$ on page 6).

Figure 2b: Switching an inductive load:

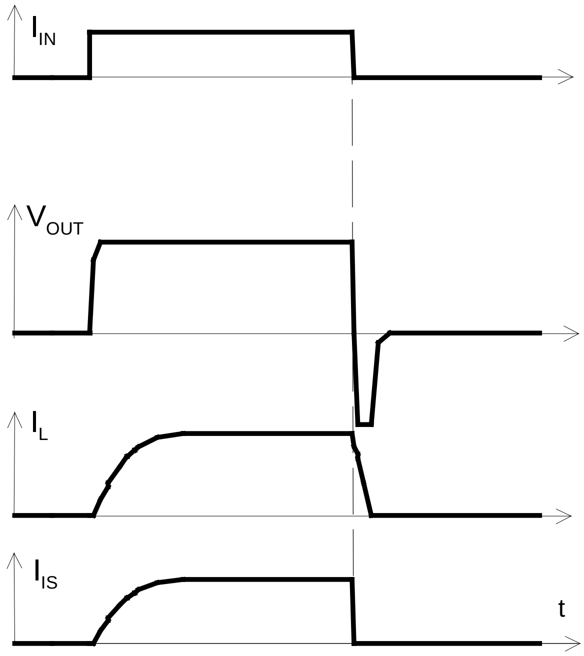
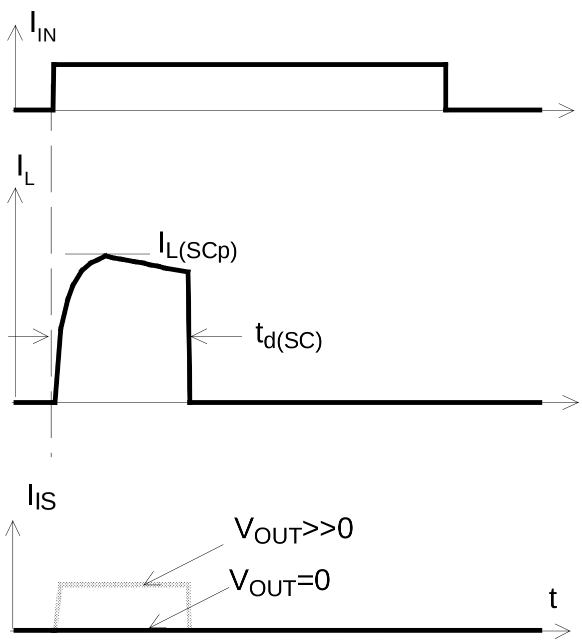


Figure 3a: Short circuit:
shut down by short circuit detection, reset by $I_{IN} = 0$.



Shut down remains latched until next reset via input.

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

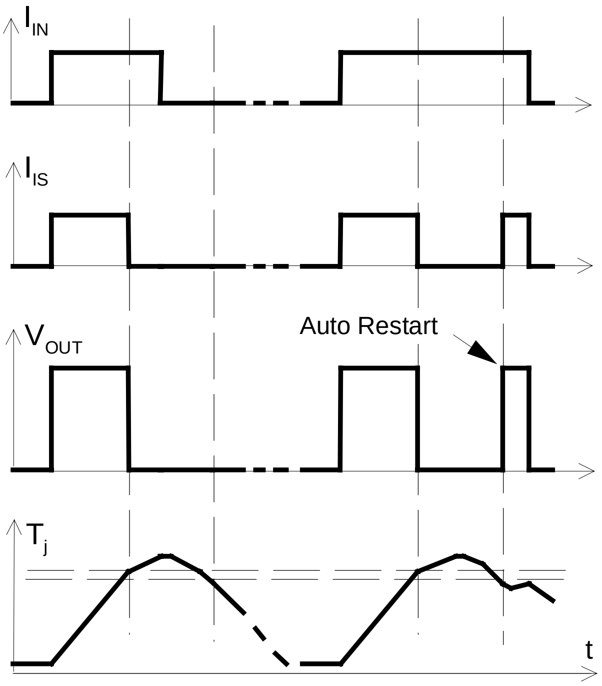
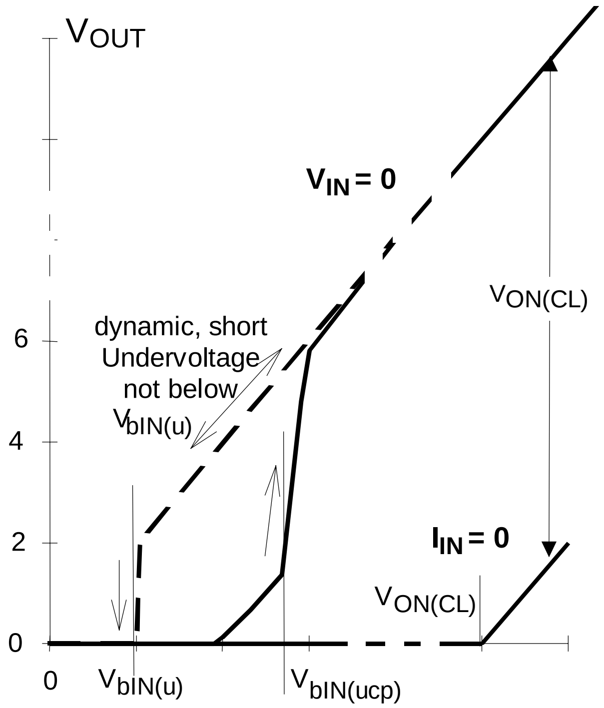


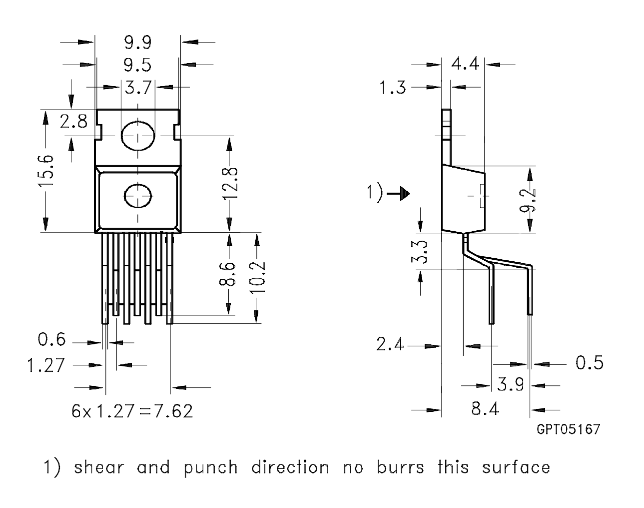
Figure 6a: Undervoltage restart of charge pump, overvoltage clamp



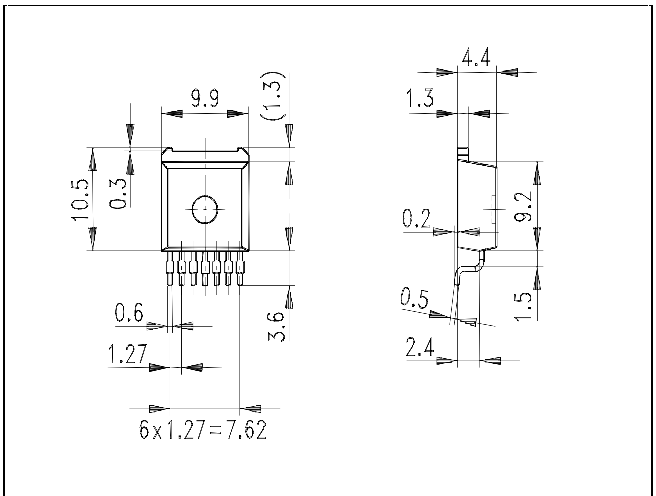
Package and Ordering Code

All dimensions in mm

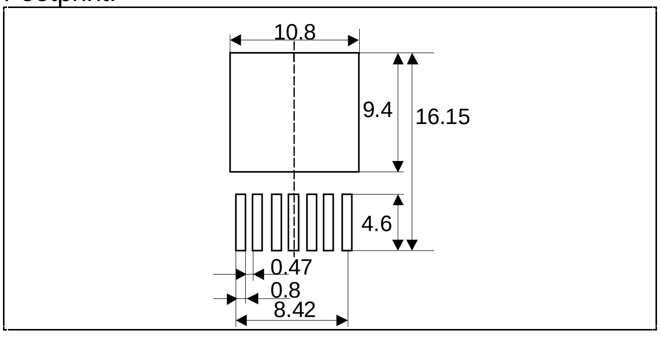
Standard TO-220AB/7	Ordering code
BTS650P	Q67060-S6308-A2



SMD TO 220AB/7, Opt. E3180		Ordering code
BTS650P E3180A	T&R:	Q67060-S6308-A4



Footprint:



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