

Smart Highside Power Switch

Features

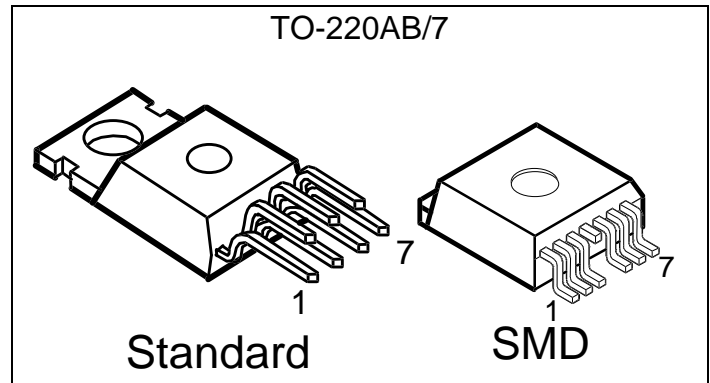
- Overload protection
- Current limitation
- Short circuit protection
- Thermal shutdown
- Overvoltage protection (including load dump)
- Fast demagnetization of inductive loads
- Reverse battery protection¹⁾
- Undervoltage and overvoltage shutdown with auto-restart and hysteresis
- Open drain diagnostic output
- Proportional load current sense
- CMOS compatible input
- Loss of ground and loss of V_{bb} protection
- Electrostatic discharge (ESD) protection

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

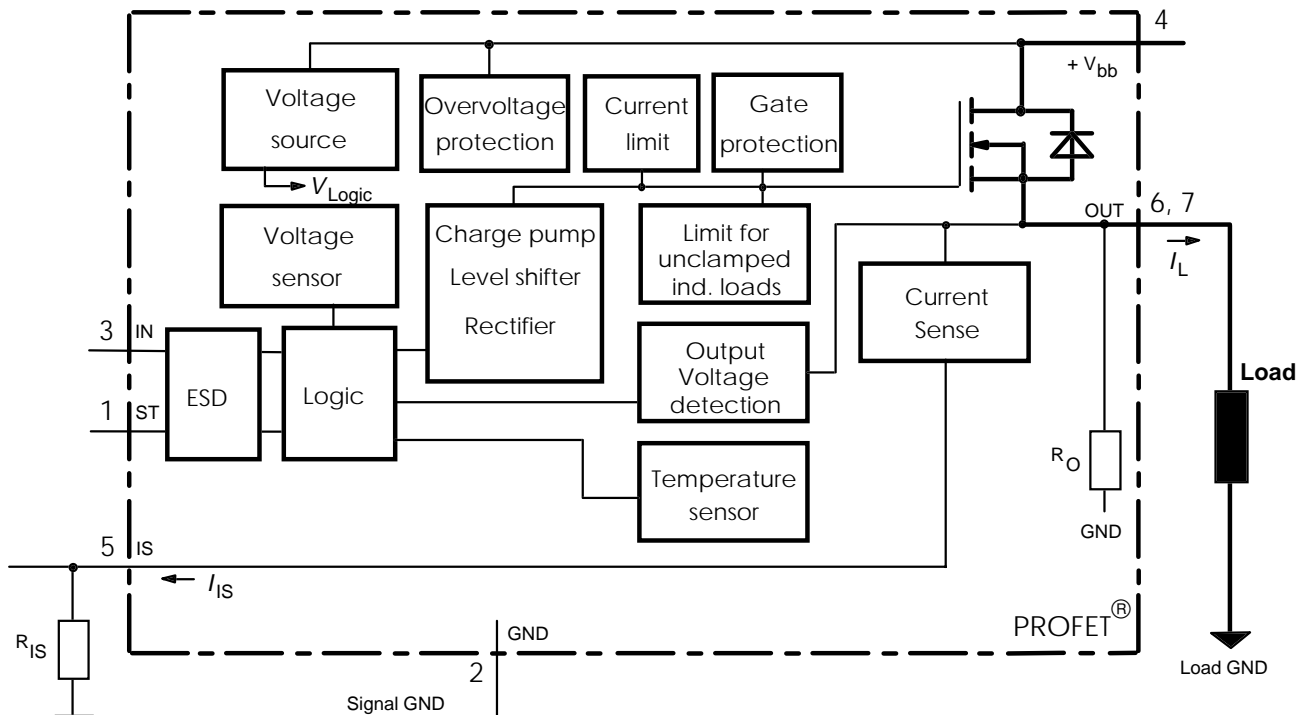
Product Summary

Overvoltage protection	$V_{bb(AZ)}$	41	V
Operating voltage	$V_{bb(on)}$	5.0 ... 34	V
On-state resistance	R_{ON}	30	m Ω
Load current (ISO)	$I_L(ISO)$	12.6	A
Current limitation	$I_L(SCr)$	24	A
Current sense ratio	I_L/I_S	5000	



General Description

N channel vertical power FET with charge pump, ground referenced CMOS compatible input and diagnostic feedback, proportional sense of load current, monolithically integrated in Smart SIPMOS[®] technology. Fully protected by embedded protection 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	ST	Diagnostic feedback, invers to input level
2	GND	Logic ground
3	IN	Input, activates the power switch in case of logical high signal
4	V _{bb}	Positive power supply voltage, the tab is shorted to this pin
5	IS	Sense current output, proportional to the load current, zero in the case of current limitation of load current
6	OUT (Load, L)	Output, protected high-side power output to the load. Both output pins have to be connected in parallel for operation according this spec (e.g. KILIS). Design the wiring for the max. short circuit current
7	OUT (Load, L)	

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

Parameter	Symbol	Values	Unit
Supply voltage (overvoltage protection see page 4)	V_{bb}	41	V
Supply voltage for full short circuit protection $T_{j\text{ start}} = -40 \dots +150\text{ °C}$	V_{bb}	30	V
Load dump protection ²⁾ $V_{\text{LoadDump}} = U_A + V_s$, $U_A = 13.5\text{ V}$ $R_1^3 = 2\ \Omega$, $R_L = 1\ \Omega$, $t_d = 200\text{ ms}$, IN= low or high	$V_{\text{Load dump}}^4)$	tbd	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}	85	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. $I_L = 12.6\text{ A}$, $Z_L = \text{tbd mH}$, $0\ \Omega$:	E_{AS}	tbd	J
Electrostatic discharge capability (ESD) (Human Body Model) acc. MIL-STD883D, method 3015.7 and ESD assn. std. S5.1-1993	IN: V_{ESD} all other pins:	1.0 8.0	kV
Input voltage (DC)	V_{IN}	-10 ... +16	V
Current through input pin (DC)	I_{IN}	± 5.0	mA
Current through status pin (DC)	I_{ST}	± 5.0	
Current through current sense pin (DC)	I_{IS}	± 14	
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_1 = 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:	R_{thJC}	--	--	1.47	K/W
	junction - ambient (free air):	R_{thJA}	--	--	75	
	SMD version, device on PCB ⁵⁾ :		--	33	--	

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.

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 4 to 6) $I_L = 5\text{ A}$	$T_j = 25\text{ °C}$: $T_j = 150\text{ °C}$:	R_{ON}	--	27 54	30 60	mΩ
Output voltage drop limitation at small load currents (pin 4 to 6), see page 13 $I_L = 0.5\text{ A}$	$T_j = -40\dots+150\text{ °C}$:	$V_{ON(NL)}$	--	50	--	mV
Nominal load current, ISO Norm (pin 4 to 6) $V_{ON} = 0.5\text{ V}$, $T_C = 85\text{ °C}$		$I_{L(ISO)}$	11.4	12.6	--	A
Nominal load current, device on PCB ⁵⁾ $T_A = 85\text{ °C}$, $T_j \leq 150\text{ °C}$ $V_{ON} \leq 0.5\text{ V}$,		$I_{L(NOM)}$	4.0	4.5	--	A
Output current (pin 6) while GND disconnected or GND pulled up, $V_{bb} = 30\text{ V}$, $V_{IN} = 0$, see diagram page 9		$I_{L(GNDhigh)}$	--	--	8	mA
Turn-on time IN \square to 90% V_{OUT} :		t_{on}	25	70	150	μs
Turn-off time IN \sqcap to 10% V_{OUT} :		t_{off}	25	80	200	
$R_L = 12\text{ Ω}$, $T_j = -40\dots+150\text{ °C}$						
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

Operating Parameters

Operating voltage ⁶⁾	$T_j = -40\dots+150\text{ °C}$:	$V_{bb(on)}$	5.0	--	34	V
Undervoltage shutdown	$T_j = -40\dots+150\text{ °C}$:	$V_{bb(under)}$	3.4	--	5.0	V
Undervoltage restart	$T_j = -40\dots+25\text{ °C}$: $T_j = +150\text{ °C}$:	$V_{bb(u\text{ rst})}$	--	4.5	5.5 6.0	V
Undervoltage restart of charge pump see diagram page 12	$T_j = -40\dots+25\text{ °C}$: $T_j = 25\dots150\text{ °C}$:	$V_{bb(ucp)}$	--	4.7	6.5 7.0	V
Undervoltage hysteresis $\Delta V_{bb(under)} = V_{bb(u\text{ rst})} - V_{bb(under)}$		$\Delta V_{bb(under)}$	--	0.5	--	V
Overvoltage shutdown	$T_j = -40\dots+150\text{ °C}$:	$V_{bb(over)}$	34	--	43	V
Overvoltage restart	$T_j = -40\dots+150\text{ °C}$:	$V_{bb(o\text{ rst})}$	33	--	--	V
Overvoltage hysteresis	$T_j = -40\dots+150\text{ °C}$:	$\Delta V_{bb(over)}$	--	1	--	V
Overvoltage protection ⁷⁾ $I_{bb} = 40\text{ mA}$	$T_j = -40\dots+150\text{ °C}$:	$V_{bb(AZ)}$	41	46	--	V

⁶⁾ At supply voltage increase up to $V_{bb} = 4.7\text{ V}$ typ without charge pump, $V_{OUT} \approx V_{bb} - 2\text{ V}$

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

Parameter and Conditions at $T_j = 25\text{ °C}$, $V_{bb} = 12\text{ V}$ unless otherwise specified	Symbol	Values			Unit
		min	typ	max	
Standby current (pin 4) $V_{IN}=0$	$I_{bb(off)}$	--	$T_j=-40\dots+25\text{ °C}$: 4	15	μA
$T_j=150\text{ °C}$:			12	25	
Leakage output current (included in $I_{bb(off)}$) $V_{IN}=0$, $T_j=-40\dots+150\text{ °C}$	$I_{L(off)}$	--	--	10	μA
Operating current (Pin 2) ⁸⁾ , $V_{IN}=5\text{ V}$	I_{GND}	--	1.2	3	mA

Protection Functions

Initial peak short circuit current limit (pin 4 to 6) $T_i=-40\text{ °C}$: $T_i=25\text{ °C}$: $T_j=+150\text{ °C}$:	$I_{L(SCp)}$	48 40 31	56 50 37	65 58 45	A
Repetitive short circuit shutdown current limit $T_j = T_{jt}$ (see timing diagrams, page 11)	$I_{L(SCr)}$	--	24	--	A
Output clamp (inductive load switch off) at $V_{OUT} = V_{bb} - V_{ON(CL)}$ $I_L = 1\text{ A}$, $T_j=-40\dots+150\text{ °C}$:	$V_{ON(CL)}$	40	47	--	V
Thermal overload trip temperature	T_{jt}	150	--	--	°C
Thermal hysteresis	ΔT_{jt}	--	10	--	K
Reverse battery (pin 4 to 2) ⁹⁾	$-V_{bb}$	--	--	32	V
Reverse battery voltage drop ($V_{out} > V_{bb}$) $I_L = -5\text{ A}$ $T_j=150\text{ °C}$:	$-V_{ON(rev)}$	--	tbd	--	mV

Diagnostic Characteristics

Current sense ratio, static on-condition, $V_{bb}-V_{out} < 1\text{ V}$, $V_{IS} = 0\dots5\text{ V}$, $V_{bb(on)} = 6.5^{10)}\dots27\text{V}$, $k_{ILIS} = I_L / I_{IS}$ $T_j = -40\text{ °C}$, $I_L = 5\text{ A}$: $T_j = -40\text{ °C}$, $I_L = 0.5\text{ A}$: $T_j = 25\dots+150\text{ °C}$, $I_L = 5\text{ A}$: $T_j = 25\dots+150\text{ °C}$, $I_L = 0.5\text{ A}$: $V_{IN} = 0$:	k_{ILIS}	4550 3300 4550 4000 --	5000 5000 5000 5000 0	6000 8000 5550 6500 --	
Sense off threshold ¹¹⁾	$V_{ON(IS)}$	1.0	1.2	--	V
Current sense output voltage limitation $T_j = -40\dots+150\text{ °C}$ $I_{IS} = 0$, $I_L = 5\text{ A}$:	$V_{IS(lim)}$	5.4	6.1	6.9	V

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

9) 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).

10) Valid if $V_{bb(u\text{ rst})}$ was exceeded before.

11) In the case of current limitation ($V_{ON} > V_{ON(IS)}$) the current sense ratio k_{ILIS} is undefined zero and the diagnostic feedback potential V_{ST} is High. See figure 2b, page 10.

Parameter and Conditions at $T_j = 25\text{ °C}$, $V_{bb} = 12\text{ V}$ unless otherwise specified	Symbol	Values			Unit
		min	typ	max	
Current sense leakage/offset current $T_j = -40 \dots +150\text{ °C}$ $V_{IN}=0, V_{IS} = 0, I_L = 0:$ $V_{IN}=5\text{ V}, V_{IS} = 0, I_L = 0:$	$I_{IS(LL)}$ $I_{IS(LH)}$	0 0	-- --	1 10	μA
Current sense settling time to $I_{IS\text{ static}} \pm 10\%$ after positive input slope, $I_L = 0 \text{ } \nearrow 5\text{ A}$, $T_j = -40 \dots +150\text{ °C}$ (not tested, specified by design)	$t_{\text{son}(IS)}$	--	--	300	μs
Current sense settling time to 10% of $I_{IS\text{ static}}$ after negative input slope, $I_L = 5 \text{ } \searrow 0\text{ A}$, $T_j = -40 \dots +150\text{ °C}$ (not tested, specified by design)	$t_{\text{soff}(IS)}$	--	30	100	μs
Current sense rise time (60% to 90%) after change of load current $I_L = 2.5 \text{ } \nearrow 5\text{ A}$ (not tested, specified by design)	$t_{\text{slc}(IS)}$	--	10	--	μs
Open load detection voltage ¹²⁾ (off-condition) $T_j = -40 \dots 150\text{ °C}:$	$V_{\text{OUT}(OL)}$	2	3	4	V
Internal output pull down (pin 6 to 2), $V_{\text{OUT}}=5\text{ V}$, $T_j=-40 \dots 150\text{ °C}$	R_O	5	15	40	$\text{k}\Omega$

Input and Status Feedback¹³⁾

Input resistance see circuit page 7	R_I	tbd	4	tbd	$\text{k}\Omega$
Input turn-on threshold voltage $\nearrow T_j = -40 \dots +150\text{ °C}:$	$V_{\text{IN}(T+)}$	--	--	3.5	V
Input turn-off threshold voltage $\searrow T_j = -40 \dots +150\text{ °C}:$	$V_{\text{IN}(T-)}$	1.5	--	--	V
Input threshold hysteresis	$\Delta V_{\text{IN}(T)}$	--	0.5	--	V
Off state input current (pin 3), $V_{\text{IN}} = 0.4\text{ V}$	$I_{\text{IN}(off)}$	1	--	50	μA
On state input current (pin 3), $V_{\text{IN}} = 5\text{ V}$	$I_{\text{IN}(on)}$	20	50	90	μA
Delay time for status with open load after Input neg. slope (see diagram page 12)	$t_{\text{d}(ST\text{ OL}3)}$	--	400	--	μs
Status delay after positive input slope (not tested, specified by design) $T_j = -40 \dots +150\text{ °C}:$	$t_{\text{don}(ST)}$	--	13	--	μs
Status delay after negative input slope (not tested, specified by design) $T_j = -40 \dots +150\text{ °C}:$	$t_{\text{doff}(ST)}$	--	1	--	μs
Status output (open drain) Zener limit voltage $T_j = -40 \dots +150\text{ °C}$, $I_{\text{ST}} = +1.6\text{ mA}:$ ST low voltage $T_j = -40 \dots +25\text{ °C}$, $I_{\text{ST}} = +1.6\text{ mA}:$ $T_j = +150\text{ °C}$, $I_{\text{ST}} = +1.6\text{ mA}:$	$V_{\text{ST}(high)}$ $V_{\text{ST}(low)}$	5.4 -- --	6.1 -- --	6.9 0.4 0.7	V
Status leakage current, $V_{\text{ST}} = 5\text{ V}$, $T_j = 25 \dots +150\text{ °C}$	$I_{\text{ST}(high)}$	--	--	2	μA

¹²⁾ External pull up resistor required for open load detection in off state.

¹³⁾ If a ground resistor R_{GND} is used, add the voltage drop across this resistor.

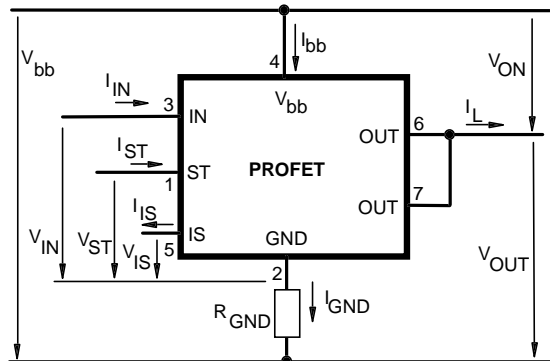
Truth Table

	Input level	Output level	Status level	Current Sense I_{IS}
Normal operation	L	L	H	0
	H	H	L	nominal
Current-limitation	L	L	H	0
	H	H ¹⁴⁾	H	>0 ¹⁴⁾
Short circuit to GND	L	L	H	0
	H	L ¹⁵⁾	H	0
Overtemperature	L	L	H	0
	H	L	H	0
Short circuit to V_{bb}	L	H	L ¹⁶⁾	0
	H	H	L	<nominal ¹⁷⁾
Open load	L	L ¹⁸⁾	H (L ¹⁹⁾)	0
	H	H	L	0
Undervoltage	L	L	H	0
	H	L	L	0
Overvoltage	L	L	H	0
	H	L	L	0
Negative output voltage clamp	L	L	H	0

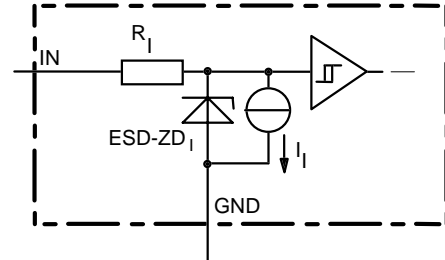
L = "Low" Level
H = "High" Level

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



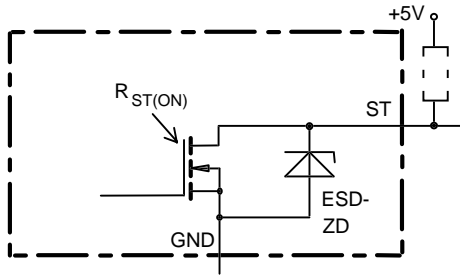
Input circuit (ESD protection)



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).

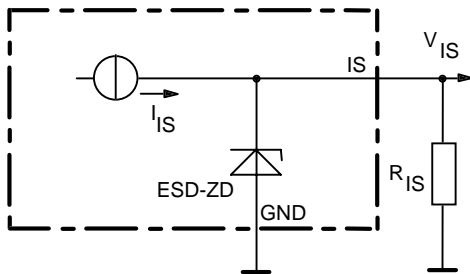
- 14) The voltage drop over the power transistor is $\text{typ. } 1.2\text{V} < V_{bb} - V_{OUT} < \text{typ. } 3\text{V}$. Under this condition the sense current I_{IS} is no longer proportional to the load current I_L .
- 15) The voltage drop over the power transistor is $V_{bb} - V_{OUT} > \text{typ. } 3\text{V}$. Under this condition the sense current I_{IS} is zero
- 16) 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 erroneous.
- 17) Low ohmic short to V_{bb} may reduce the output current I_L and therefore also the sense current I_{IS} .
- 18) Power Transistor off, high impedance
- 19) with external resistor between pin 4 and pin 6

Status output



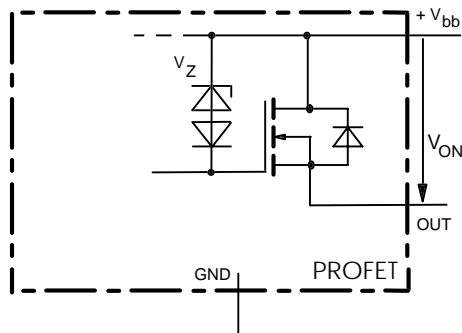
ESD-Zener diode: 6.1 V typ., max 5 mA;
 $R_{ST(ON)} < 440 \Omega$ at 1.6 mA, ESD zener diodes are not to be used as voltage clamp at DC conditions. Operation in this mode may result in a drift of the zener voltage (increase of up to 1 V).

Current sense output



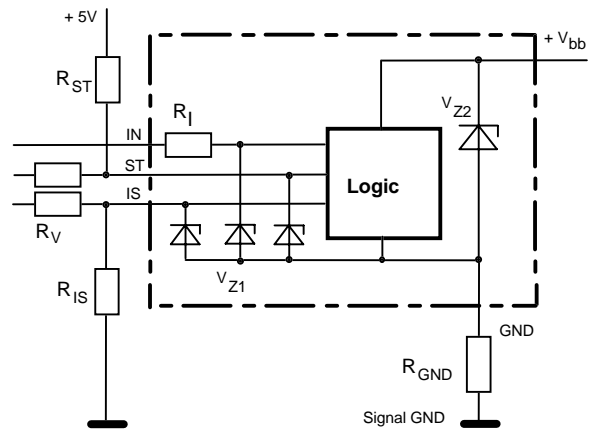
ESD-Zener diode: 6.1 V typ., max 14 mA;
 $R_{IS} = 1 \text{ k}\Omega$ nominal

Inductive and overvoltage output clamp



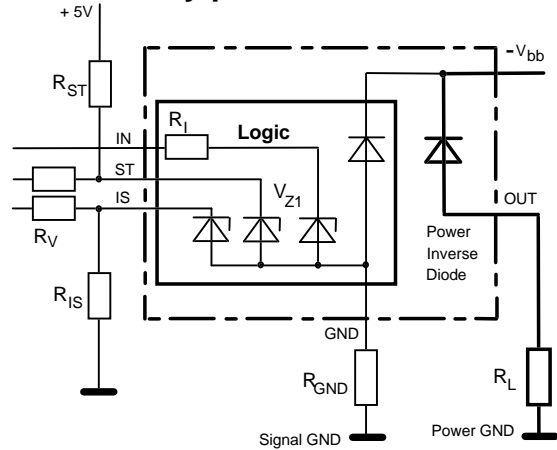
V_{ON} clamped to 47 V typ.

Overvoltage protection of logic part



$V_{Z1} = 6.1 \text{ V typ.}$, $V_{Z2} = 46 \text{ V typ.}$, $R_I = 4 \text{ k}\Omega \text{ typ.}$,
 $R_{GND} = 150 \Omega$, $R_{ST} = 15 \text{ k}\Omega$, $R_{IS} = 1 \text{ k}\Omega$, $R_V = 15 \text{ k}\Omega$,

Reverse battery protection

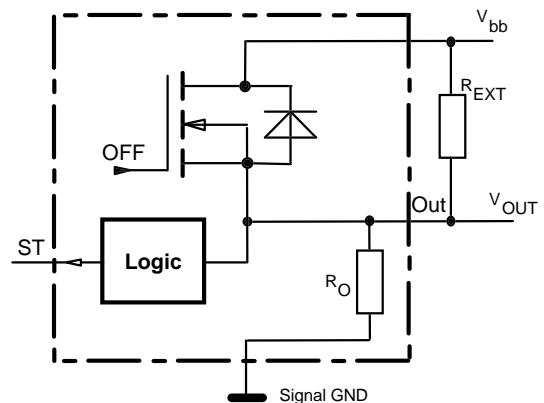


The load R_L is inverse on, temperature protection is not active

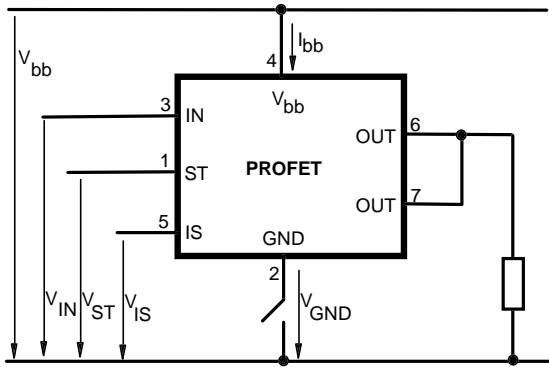
$R_{GND} = 150 \Omega$, $R_I = 4 \text{ k}\Omega \text{ typ.}$, $R_{ST} \geq 500 \Omega$, $R_{IS} \geq 200 \Omega$,
 $R_V \geq 500 \Omega$,

Open-load detection

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

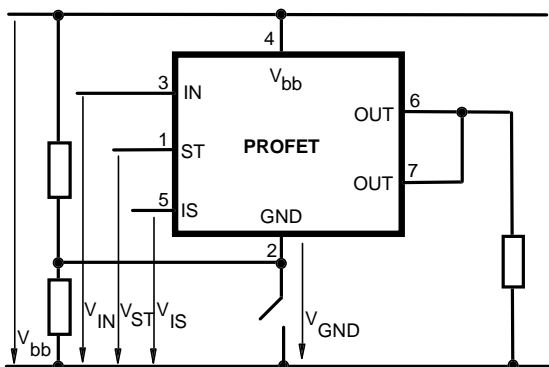


GND disconnect



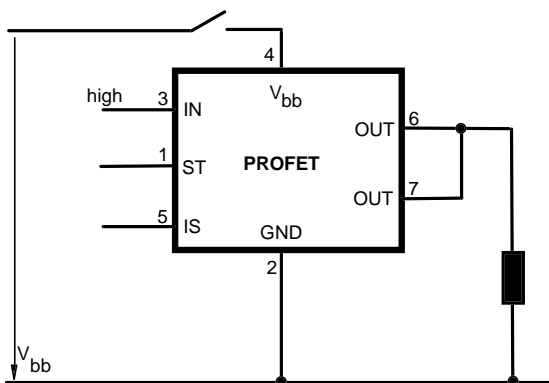
Any kind of load. In case of Input=high is $V_{OUT} \approx V_{IN} - V_{IN(T+)}$.
Due to $V_{GND} > 0$, no $V_{ST} = \text{low}$ signal available.

GND disconnect with GND pull up



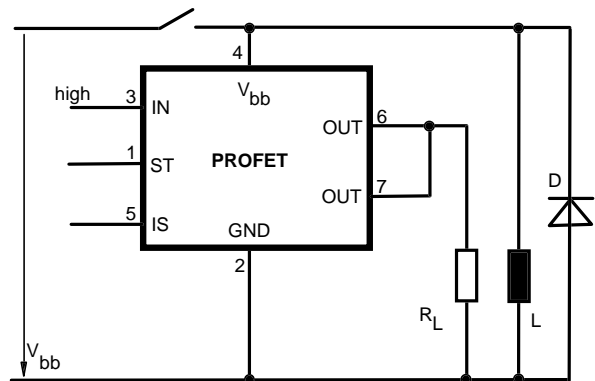
Any kind of load. If $V_{GND} > V_{IN} - V_{IN(T+)}$ device stays off
Due to $V_{GND} > 0$, no $V_{ST} = \text{low}$ signal available.

V_{bb} disconnect with energized inductive load



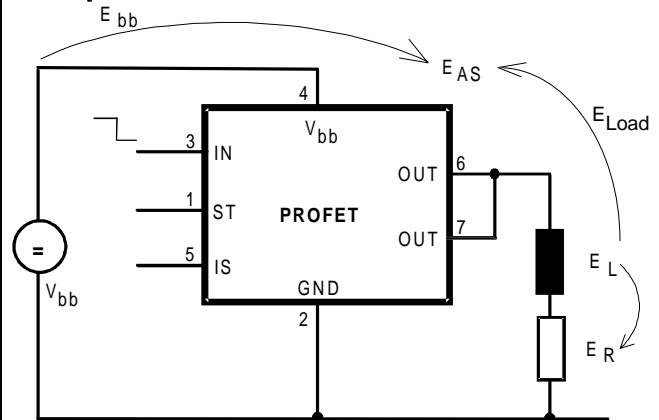
Normal load current can be handled by the PROFET itself.

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

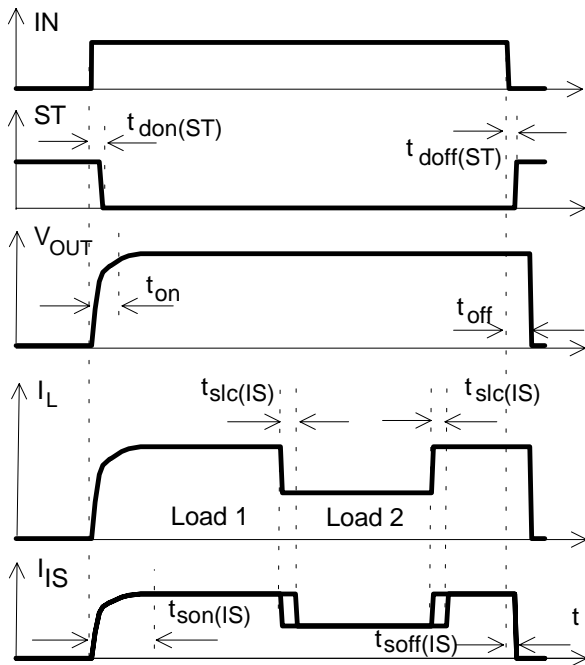
$$E_{AS} = E_{bb} + E_L - E_R = \int V_{ON(CL)} \cdot i_L(t) dt,$$

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

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

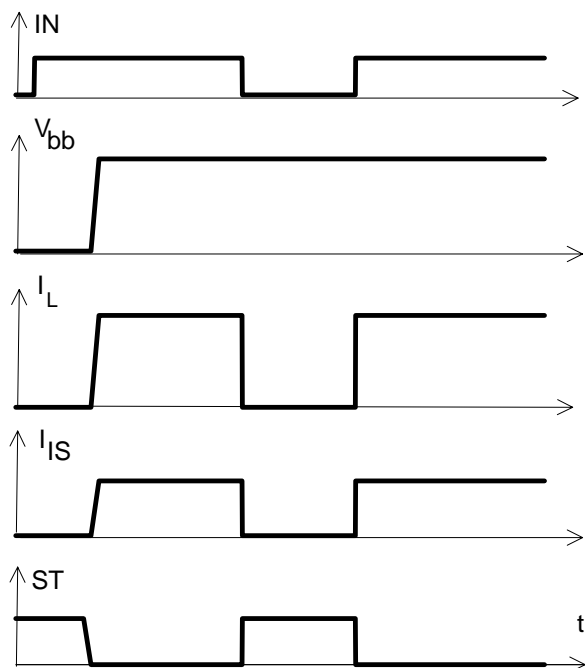
Timing diagrams

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



The sense signal is not valid during settling time after turn on or change of load current.

Figure 1b: V_{bb} turn on:



proper turn on under all conditions

Figure 2a: Switching a lamp

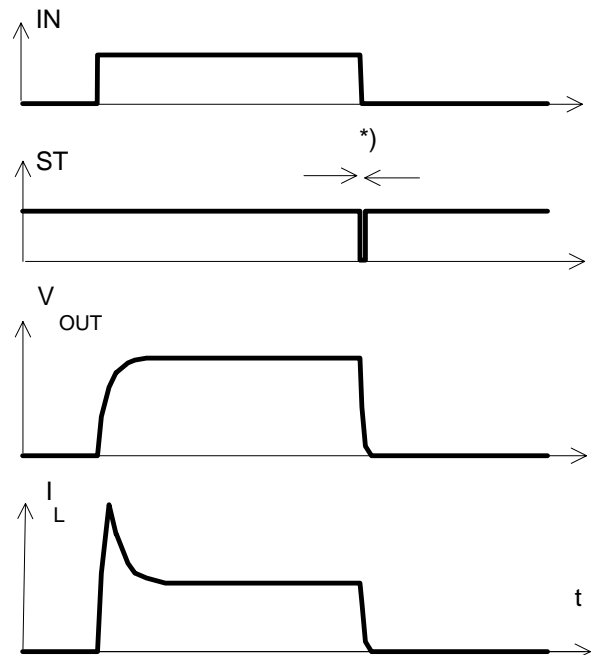


Figure 2b: Switching a lamp with current limit:

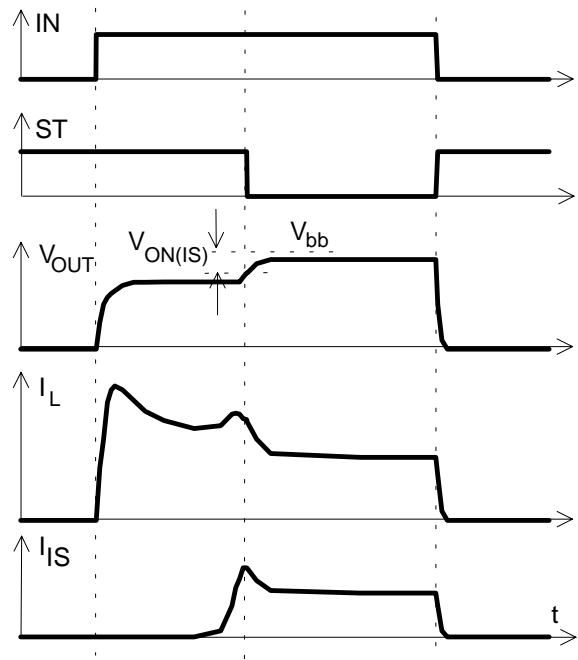


Figure 2c: Switching an inductive load:

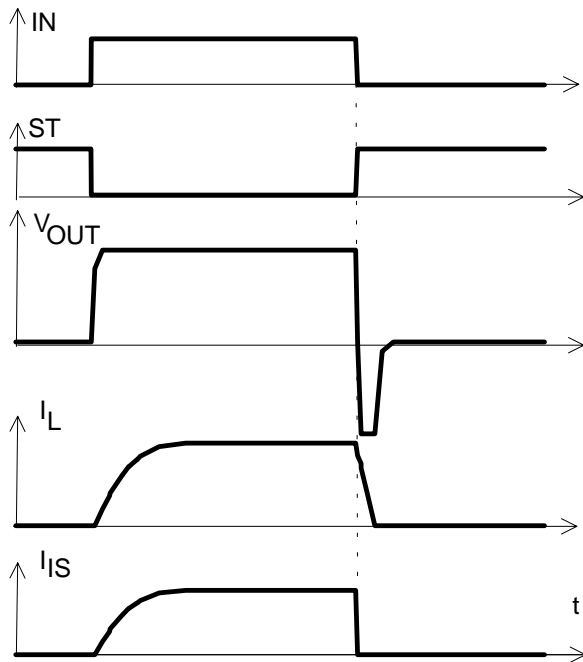
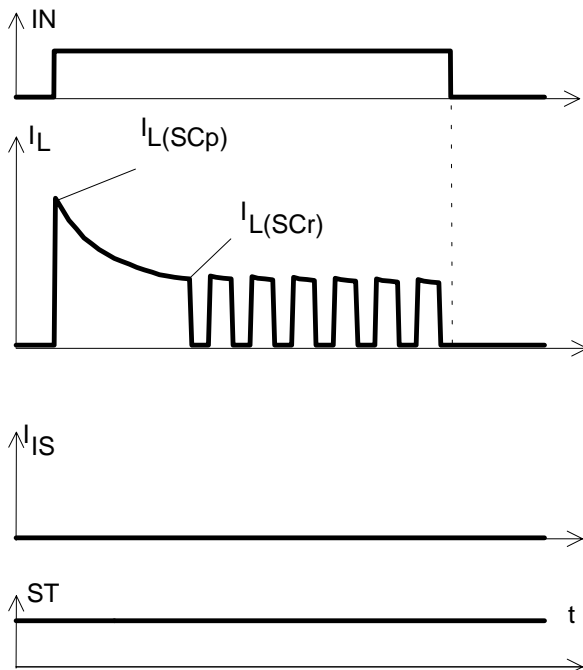


Figure 3a: Short circuit: shut down by overtemperature, reset by cooling



Heating up may require several milliseconds, depending on external conditions
 $I_{L(SCp)} = 50 \text{ A}$ typ. increases with decreasing temperature.

Figure 4a: Overtemperature:

Reset if $T_j < T_{jt}$

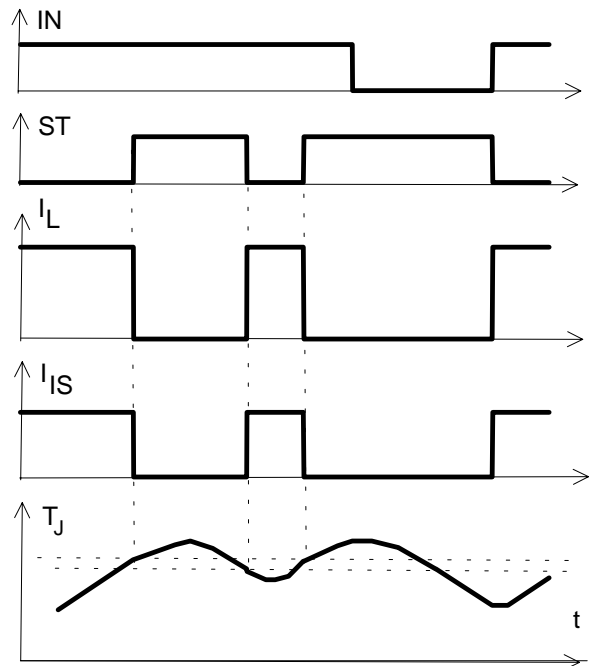


Figure 5a: Open load: detection in ON-state, open load occurs in on-state

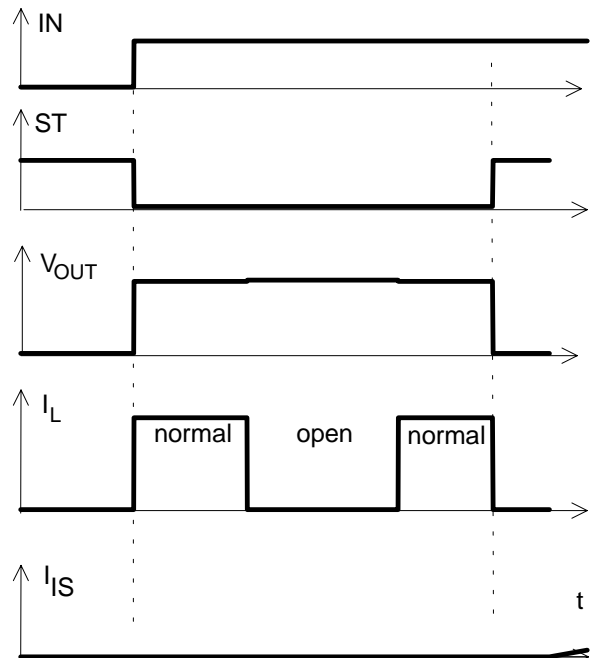


Figure 5b: Open load: detection in ON- and OFF-state (with R_{EXT}), turn on/off to open load

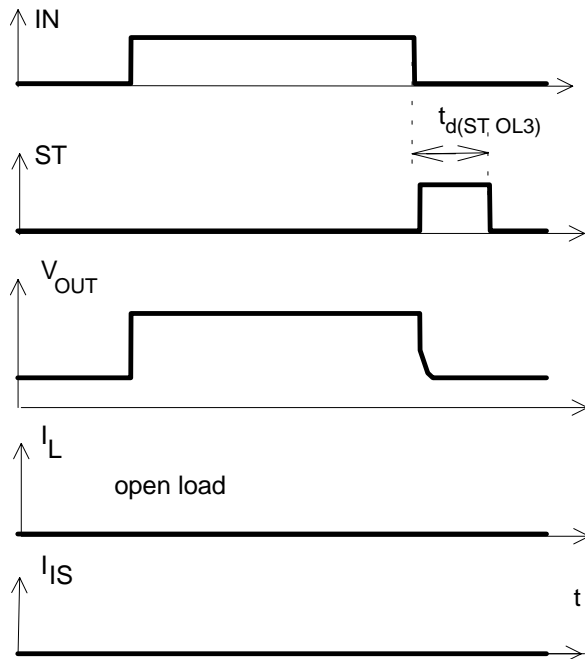


Figure 6a: Undervoltage:

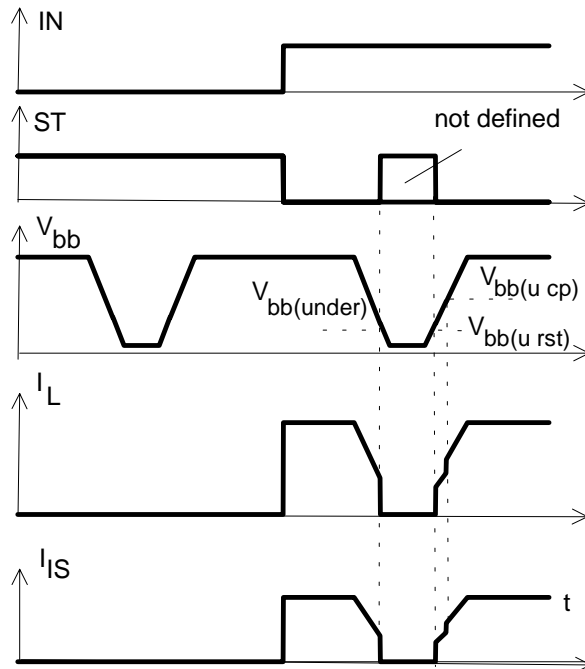


Figure 6b: Undervoltage restart of charge pump

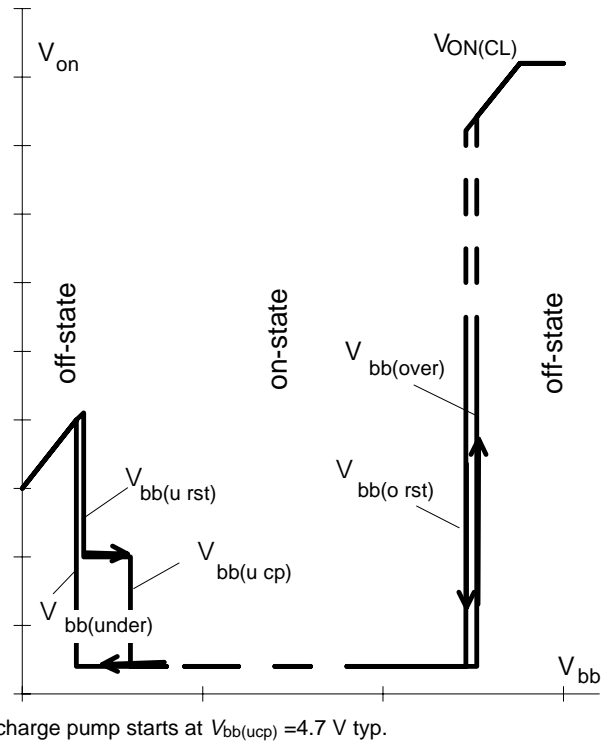


Figure 7a: Overvoltage:

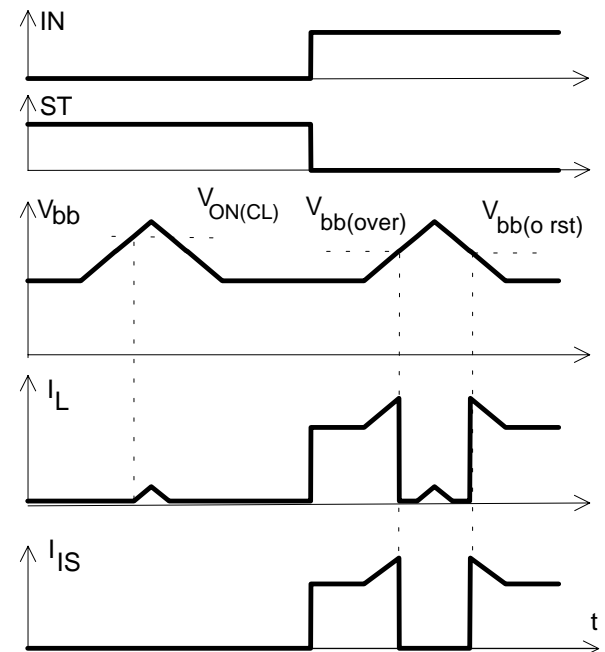


Figure 8a: Current sense versus load current:

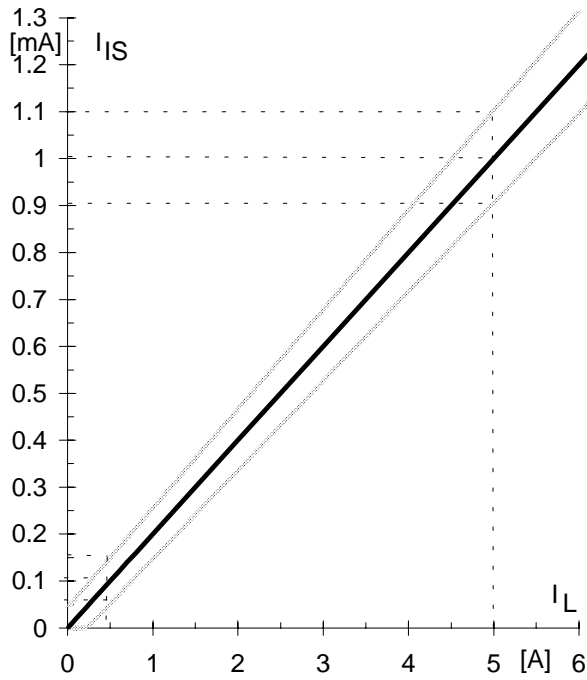


Figure 9a: Output voltage drop versus load current:

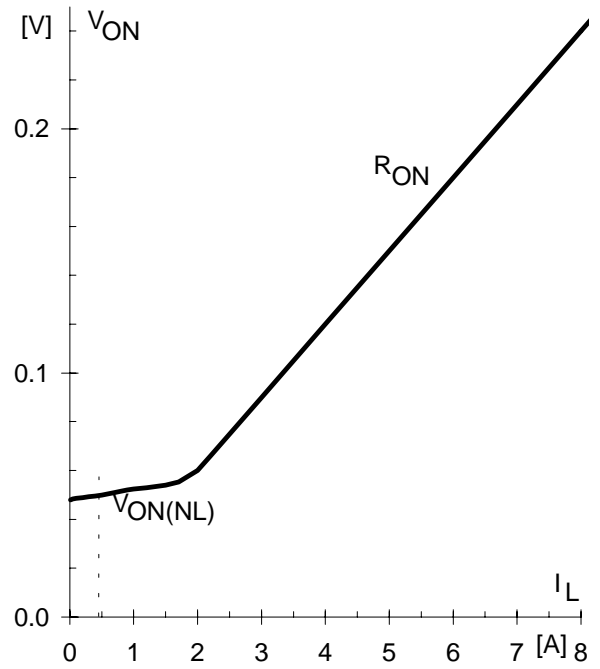
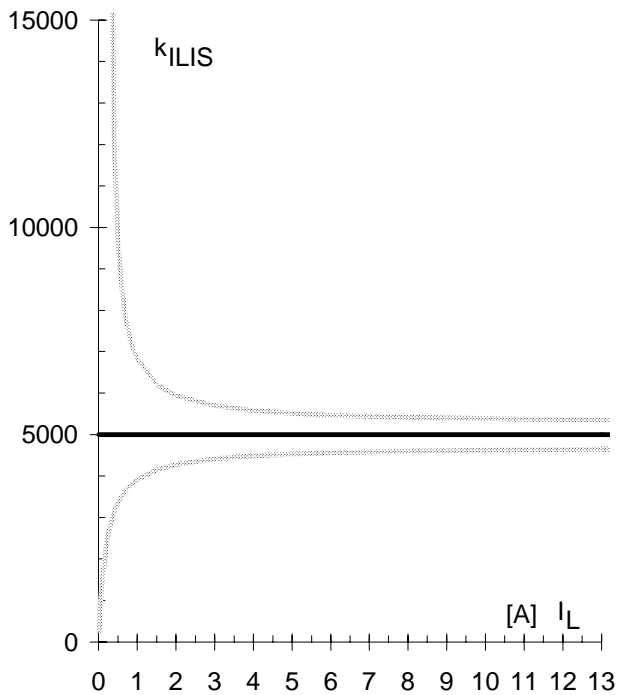


Figure 8b: Current sense ratio:

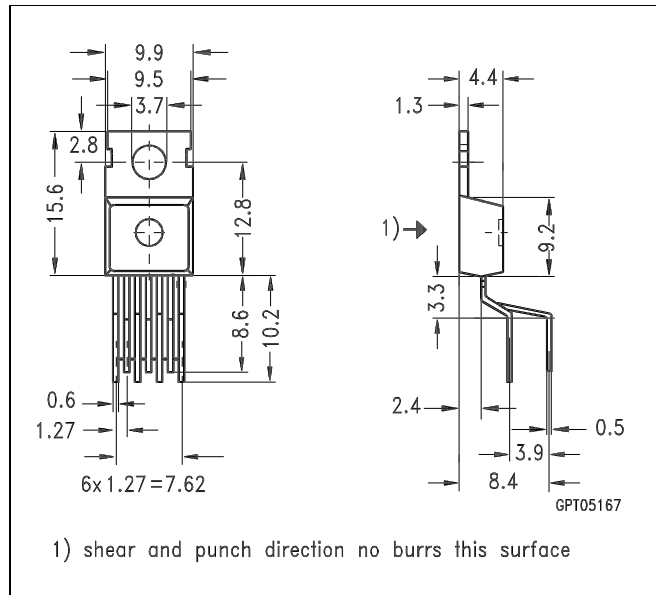


Package and Ordering Code

All dimensions in mm

Standard TO-220AB/7 Ordering code

BTS640S2	Q67060-S6307-A2
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SMD TO 220AB/7, Opt. E3128 Ordering code

BTS640S2 E3128A	T&R: Q67060-S6307-A3
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