

Smart Highside High Current Power Switch

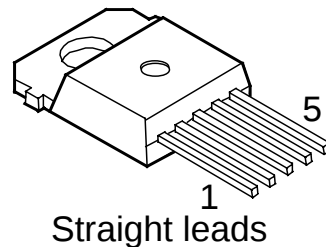
Features

- 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} protection²⁾
- **Electrostatic discharge (ESD)** protection

Product Summary

Overvoltage protection	$V_{bb(AZ)}$	70	V
Output clamp	$V_{ON(CL)}$	60	V
Operating voltage	$V_{bb(on)}$	5.0 ... 55	V
On-state resistance	R_{ON}	4	mΩ
Load current (ISO)	$I_L(ISO)$	96	A
Short circuit current limitation	$I_L(SCp)$	320	A
Current sense ratio	$I_L : I_{IS}$	25 000	

TO-218AB/5

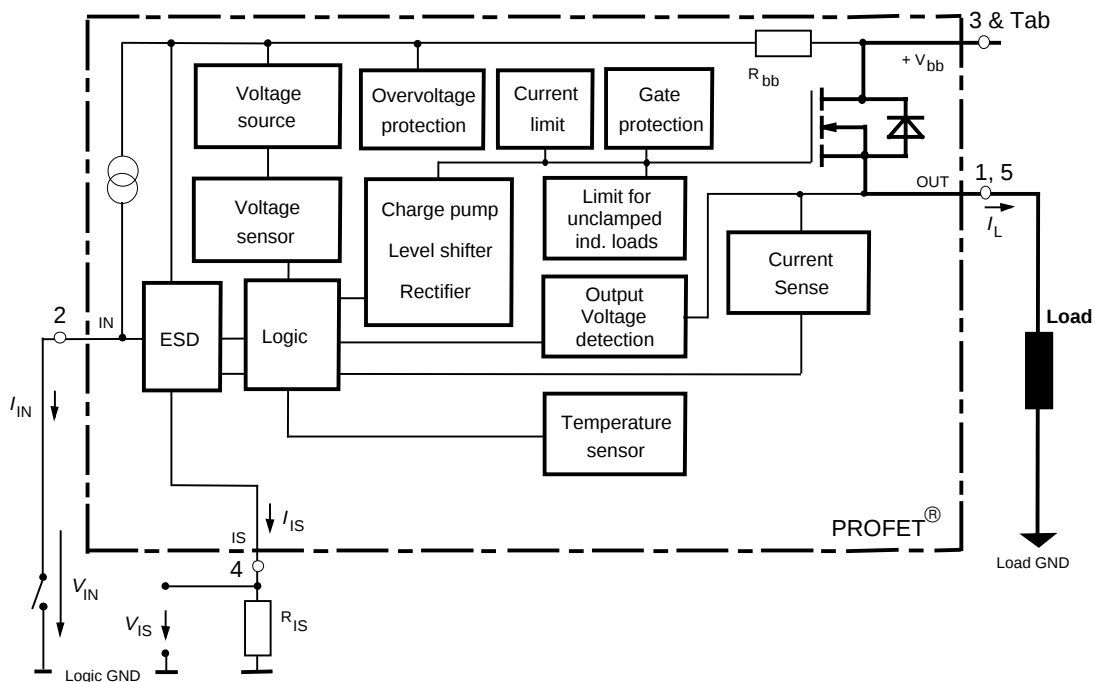


Application

- Power switch with current sense diagnostic feedback for up to 48 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 8).

Pin	Symbol	Function
1	OUT O	Output to the load. The pins 1 and 5 must be shorted with each other especially in high current applications! ³⁾
2	IN I	Input, activates the power switch in case of short to ground
3	V _{bb} +	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⁾ .
4	IS S	Diagnostic feedback providing a sense current proportional to the load current; zero current on failure (see Truth Table on page 6)
5	OUT O	Output to the load. The pins 1 and 5 must be shorted with each other especially in high current applications! ³⁾

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

Parameter	Symbol	Values	Unit
Supply voltage (overvoltage protection see page 4)	V _{bb}	60	V
Supply voltage for full short circuit protection, resistive load or $L < \text{tbd } \mu\text{H}$ $T_{j,\text{start}} = -40 \dots +150^\circ\text{C}$:	V _{bb}	55	V
Load current (short circuit current, see page 4)	I _L	self-limited	A
Load dump protection $V_{\text{LoadDump}} = U_A + V_S$, $U_A = 13.5\text{ V}$ $R_l^{5)} = 2\ \Omega$, $R_L = 0.1\ \Omega$, $t_d = 200\text{ ms}$, IN, IS = open or grounded	V _{Load dump} ⁶⁾	80	V
Operating temperature range	T _j	-40 ... +150	°C
Storage temperature range	T _{stg}	-55 ... +150	°C
Power dissipation (DC), $T_C \leq 25^\circ\text{C}$	P _{tot}	310	W
Inductive load switch-off energy dissipation, single pulse $V_{bb} = 12\text{ V}$, $T_{j,\text{start}} = 150^\circ\text{C}$, $T_C = 150^\circ\text{C}$ const., $I_L = \text{tbd}$ (≥ 20) A, $Z_L = \text{tbd mH}$, $0\ \Omega$, see diagrams on page 9	E _{AS}	tbd	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 k Ω	V _{ESD}	2.0	kV
Current through input pin (DC)	I _{IN}	+15, -250	mA
Current through current sense status pin (DC) see internal circuit diagrams on page 7	I _{IS}	+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 0.5 m Ω (depending on used length of the pin) to the R_{ON} if the pin is used instead of the tab.

⁵⁾ R_l = 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: junction - ambient (free air):	$R_{thJC}^{(7)}$	--	--	0.40	K/W
	R_{thJA}	--	30	--	

Electrical Characteristics

Parameter and Conditions at $T_j = -40 \dots +150^\circ\text{C}$, $V_{bb} = 12\text{ V}$ unless otherwise specified	Symbol	Values			Unit
		min	typ	max	

Load Switching Capabilities and Characteristics

On-state resistance (Tab to pins 1,5, see measurement circuit page 7) $I_L = \text{tbd } (>=20)\text{ A}$, $T_j = 25^\circ\text{C}$: $V_{IN} = 0$, $I_L = \text{tbd } (>=20)\text{ A}$, $T_j = 150^\circ\text{C}$: $I_L = 150\text{ A}$, $T_j = 150^\circ\text{C}$:	R_{ON}	--	3.3 6.5	4.0 7.8 7.9	$\text{m}\Omega$
Nominal load current ⁸⁾ (Tab to pins 1,5) ISO 10483-1/6.7: $V_{ON} = 0.5\text{ V}$, $T_C = 85^\circ\text{C}$ ⁹⁾	$I_{L(ISO)}$	80	96	--	A
Maximum load current in resistive range (Tab to pins 1,5) $V_{ON} = 1.8\text{ V}$, $T_C = 25^\circ\text{C}$: see diagram on page 12 $V_{ON} = 1.8\text{ V}$, $T_C = 150^\circ\text{C}$:	$I_{L(Max)}$	tbd tbd	-- --	-- --	A
Turn-on time ¹⁰⁾ $I_{IN} \uparrow$ to 90% V_{OUT} :	t_{on}	130	--	550	μs
Turn-off time $I_{IN} \downarrow$ to 10% V_{OUT} : $R_L = 1\ \Omega$, $T_j = -40\dots+150^\circ\text{C}$	t_{off}	60	--	240	
Slew rate on ¹⁰⁾ (10 to 30% V_{OUT}) $R_L = 1\ \Omega$	dV/dt_{on}	--	0.8	--	$\text{V}/\mu\text{s}$
Slew rate off ¹⁰⁾ (70 to 40% V_{OUT}) $R_L = 1\ \Omega$	$-dV/dt_{off}$	--	0.8	--	$\text{V}/\mu\text{s}$

Inverse Load Current Operation

On-state resistance (Pins 1,5 to pin 3) $V_{bIN} = 12\text{ V}$, $I_L = -\text{tbd } (>=20)\text{ A}$ see diagram on page 9 $T_j = 25^\circ\text{C}$: $T_j = 150^\circ\text{C}$:	$R_{ON(inv)}$	--	3.3 6.5	4.0 7.8	$\text{m}\Omega$
Nominal inverse load current (Pins 1,5 to Tab) $V_{ON} = -0.5\text{ V}$, $T_C = 85^\circ\text{C}$ ⁹⁾	$I_{L(inv)}$	80	96	--	A
Drain-source diode voltage ($V_{out} > V_{bb}$) $I_L = -\text{tbd } (>=20)\text{ A}$, $I_{IN} = 0$, $T_j = +150^\circ\text{C}$	$-V_{ON}$	--	tbd	--	mV

⁷⁾ Thermal resistance R_{thCH} case to heatsink (about 0.25 K/W with silicone paste) not included!

⁸⁾ Not tested, specified by design.

⁹⁾ T_j is about 105°C under these conditions.

¹⁰⁾ See timing diagram on page 13.

Parameter and Conditions at $T_j = -40 \dots +150^\circ\text{C}$, $V_{bb} = 12\text{ V}$ unless otherwise specified	Symbol	Values			Unit
		min	typ	max	

Operating Parameters

Operating voltage ($V_{IN} = 0$) ¹¹⁾	$V_{bb(on)}$	5.0	--	55	V
Undervoltage shutdown ¹²⁾	$V_{bIN(u)}$	--	3.5	4.5	V
Undervoltage start of charge pump see diagram page 14	$V_{bIN(ucp)}$	--	5	6.5	V
Overvoltage protection ¹³⁾	$V_{bIN(z)}$	$T_j = -40^\circ\text{C}$: $I_{bb} = 15\text{ mA}$	68	--	V
		$T_j = 25\dots+150^\circ\text{C}$:	70	74	
Standby current	$I_{bb(off)}$	$T_j = -40\dots+25^\circ\text{C}$:	--	15	μA
$I_{IN} = 0$		$T_j = 150^\circ\text{C}$:	--	25	

Protection Functions

Short circuit current limit (Tab to pins 1,5) $V_{ON} = 12\text{ V}$, time until shutdown max. 300 μs	$I_{L(SCp)}$	$T_c = -40^\circ\text{C}$:	--	370	--	A
		$T_c = 25^\circ\text{C}$:	tbd	320	tbd	
		$T_c = +150^\circ\text{C}$:	tbd	225	tbd	
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	--	300	μs
Output clamp ¹⁴⁾ (inductive load switch off) (typ. $I_{IS} = -120\mu\text{A}$)	$-V_{OUT(CL)}$	$I_L = 40\text{ mA}$:	--	15	--	V
		$I_L = 20\text{ A}$:	--	17	--	
Output clamp (inductive load switch off) at $V_{OUT} = V_{bb} - V_{ON(CL)}$ (e.g. overvoltage) $I_L = 40\text{ mA}$	$V_{ON(CL)}$		60	64	68	V
Short circuit shutdown detection voltage (pin 3 to pins 1,5)	$V_{ON(SC)}$		--	6	--	V

¹¹⁾ For all voltages 0 ... 55 V the device is fully protected against overtemperature and short circuit.

¹²⁾ $V_{bIN} = V_{bb} - V_{IN}$ see diagram on page 7. When V_{bIN} increases from less than $V_{bIN(u)}$ up to $V_{bIN(ucp)} = 5\text{ V}$ (typ.) the charge pump is not active and $V_{OUT} \approx V_{bb} - 3\text{ V}$.

¹³⁾ See also $V_{ON(CL)}$ in circuit diagram on page 8.

¹⁴⁾ This output clamp can be "switched off" by using an additional diode at the IS-Pin (see page 7). If the diode is used, V_{OUT} is clamped to $V_{bb} - V_{ON(CL)}$ at inductive load switch off.

Parameter and Conditions at $T_j = -40 \dots +150^\circ\text{C}$, $V_{bb} = 12\text{V}$ unless otherwise specified	Symbol	Values			Unit
		min	typ	max	
Thermal overload trip temperature	T_{jt}	150	--	--	$^\circ\text{C}$
Thermal hysteresis	ΔT_{jt}	--	10	--	K

Reverse Battery

Reverse battery voltage ¹⁵⁾	$-V_{bb}$	--	--	42	V
On-state resistance (Pins 1,5 to pin 3) $T_j = 25^\circ\text{C}$: $V_{bb} = -12\text{V}$, $V_{IN} = 0$, $I_L = -\text{tbd}$ (≥ 20) A, $R_{IS} = 1\text{k}\Omega$ $T_j = 150^\circ\text{C}$:	$R_{ON(\text{rev})}$	--	3.7 0	tbd 0	m Ω
Integrated resistor in V_{bb} line	R_{bb}	--	tbd	--	Ω

Diagnostic Characteristics

Current sense ratio, static on-condition, $k_{ILIS} = I_L : I_{IS}$, $V_{ON} < 1.5\text{ V}^{16)}$, $V_{IS} < V_{OUT} - 5\text{ V}$, $V_{bIN} > 4.5\text{ V}$ see diagram on page 11 $I_{IN} = 0$, $I_{IS}=0$ (e.g. during deenergizing of inductive loads):	-40°C: 25°C: 150°C: $I_L = 150\text{ A}$: $I_L = 25\text{ A}$: $I_L = 12\text{ A}$: $I_L = 6\text{ A}$:	k_{ILIS}	-- -- -- -40°C: $\pm 4.5\%$ $\pm 8.9\%$ $\pm 15\%$ $\pm 46\%$	26 530 25 430 23 520 +25°C: $\pm 4.2\%$ $\pm 7.5\%$ $\pm 12\%$ $\pm 36\%$	-- -- -- 150°C: $\pm 4.0\%$ $\pm 6.1\%$ $\pm 9.0\%$ $\pm 24\%$	
Sense current saturation		$I_{IS,lim}$	5.5	--	--	mA
Current sense leakage current $I_{IN} = 0$, $V_{IS} = 0$: $V_{IN} = 0$, $V_{IS} = 0$, $I_L \leq 0$:	$I_{IS(LL)}$ $I_{IS(LH)}$	-- --	-- 2	0.5 --	μA	
Current sense settling time ¹⁷⁾ after positive input slope (90% of I_{IS} static) $I_L = 0 / \text{tbd} (>=20)\text{ A}$:	$t_{son(IS)}$	--	tbd	500	μs	
Current sense settling time ¹⁷⁾ after negative input slope (10% of I_{IS} static) $I_L = \text{tbd} (>=20) / 0\text{ A}$:	$t_{soff(IS)}$	--	tbd	500	μs	
Current sense settling time ¹⁷⁾ after change of load current (60% to 90%) $I_L = 15 / \text{tbd} (>=20)\text{ A}$:	$t_{slc(IS)}$	--	tbd	500	μs	
Overvoltage protection $I_{bb} = 15\text{ mA}$	$T_j = -40^\circ\text{C}$: $T_j = 25...+150^\circ\text{C}$:	$V_{bIS(Z)}$	68 70	-- 74	-- --	V

¹⁵⁾ 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 8.

¹⁶⁾ If V_{ON} is higher, the sense current is no longer proportional to the load current due to sense current saturation, see $I_{IS,lim}$.

¹⁷⁾ Not tested, specified by design.

Parameter and Conditions at $T_j = -40 \dots +150^\circ\text{C}$, $V_{bb} = 12\text{V}$ unless otherwise specified	Symbol	Values			Unit
		min	typ	max	

Input

Input and operating current (see diagram page 12) IN grounded ($V_{IN} = 0$)	$I_{IN(on)}$	--	1	2	mA
Input current for turn-off ¹⁸⁾	$I_{IN(off)}$	--	--	40	μA

Truth Table

	Input current level	Output level	Current Sense I_{IS}	Remark
Normal operation	L H	L H	0 nominal	$=I_L / k_{IIS}$, 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 occur
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 ¹⁹⁾	
Open load	L H	Z ²⁰⁾ 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 via input: $I_{IN}=\text{low}$ and $T_j < T_{jt}$ (see diagram on page 15)

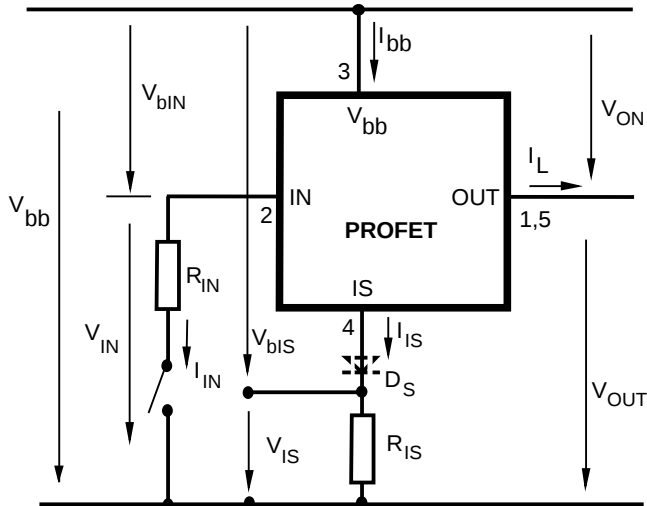
Short circuit to GND: Shutdown remains latched until next reset via input (see diagram on page 13)

¹⁸⁾ We recommend the resistance between IN and GND to be less than 0.5 k Ω for turn-on and more than 500k Ω for turn-off. Consider that when the device is switched off ($I_{IN} = 0$) the voltage between IN and GND reaches almost V_{bb} .

¹⁹⁾ Low ohmic short to V_{bb} may reduce the output current I_L and can thus be detected via the sense current I_{IS} .

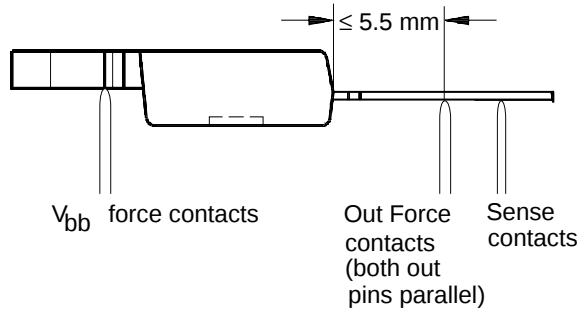
²⁰⁾ Power Transistor "OFF", potential defined by external impedance.

Terms

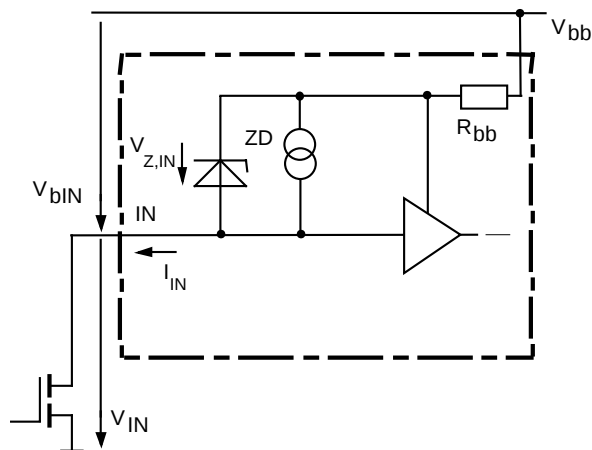


Two or more devices can easily be connected in parallel to increase load current capability.

R_{ON} measurement layout



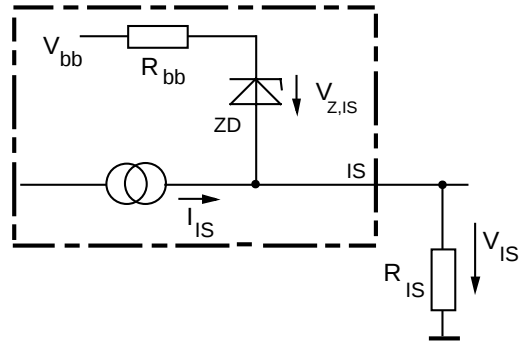
Input circuit (ESD protection)



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} = 74 V (typ.).

Current sense status output



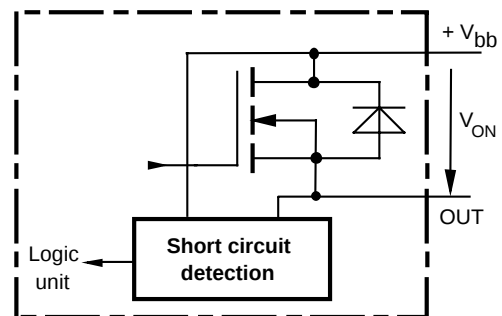
V_{Z,IS} = 74 V (typ.), R_{IS} = 1 kΩ nominal (or 1 kΩ / n, if n devices are connected in parallel). I_S = I_L / k_{ILIS} can be only driven by the internal circuit as long as V_{out} - V_{IS} > 5 V. If you want to measure load currents up to

I_{L(M)}, R_{IS} should be less than $\frac{V_{bb} - 5 \text{ V}}{I_{L(M)} / k_{ILIS}}$.

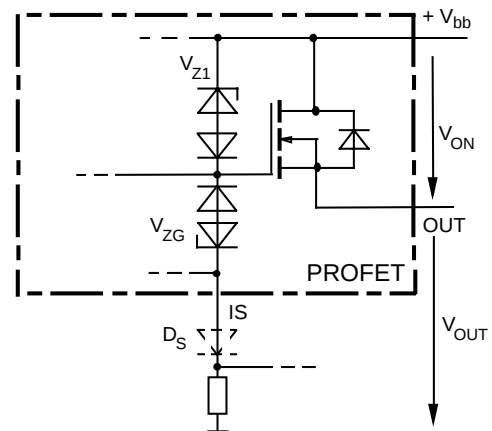
Note: For large values of R_{IS} the voltage V_{IS} can reach almost V_{bb}. See also overvoltage protection. If you don't use the current sense output in your application, you can leave it open.

Short circuit detection

Fault Condition: V_{ON} > V_{ON(SC)} (6 V typ.) and t > t_{d(SC)} (80 ... 300 μs).



Inductive and overvoltage output clamp



V_{ON} is clamped to V_{ON(CL)} = 62 V typ. At inductive load switch-off without D_S, V_{OUT} is clamped to V_{OUT(CL)} = -15 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

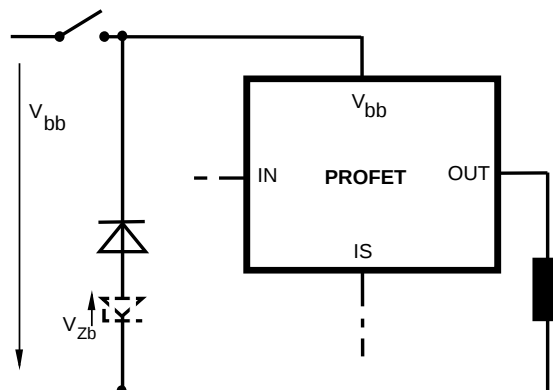
V_{bb} disconnect with energized inductive load

Provide a current path with load current capability by using a diode, a Z-diode, or a varistor. ($V_{ZL} < 70 \text{ V}$ or $V_{Zb} < 42 \text{ V}$ if $R_{IN}=0$). For higher clamp voltages currents at IN and IS have to be limited to 250 mA.



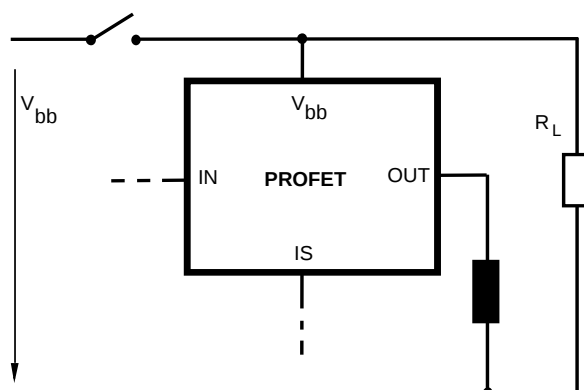
The diagram shows a PROFET (Power MOSFET) driver circuit. The gate is connected to V_{bb} through a switch. The drain is connected to V_{bb} . The source is connected to I_S and a diode. The diode is connected to V_{ZL} . The output is connected to the load.

Version b:

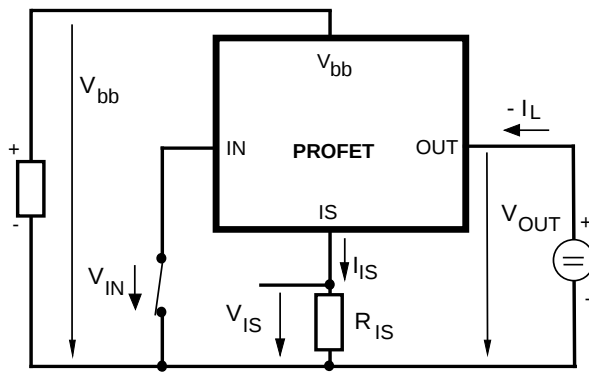


Note that there is no reverse battery protection when using a diode without additional Z-diode V_{Z1} , V_{Zb} .

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



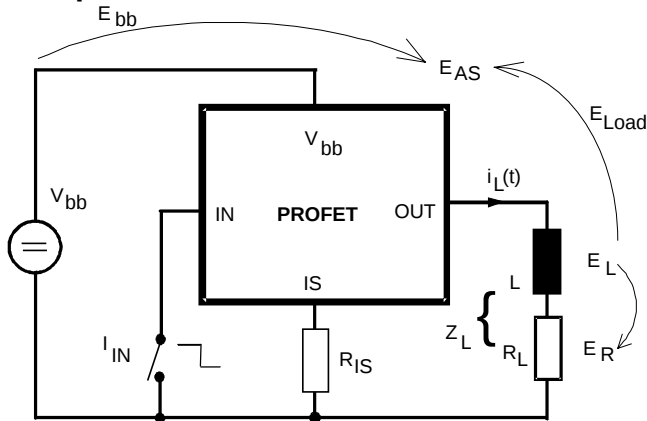
Inverse load current operation



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 $R_{ON(INV)} \cdot I^2$ (specifications see page 3).

Note: Temperature protection during inverse load current operation is not possible!

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

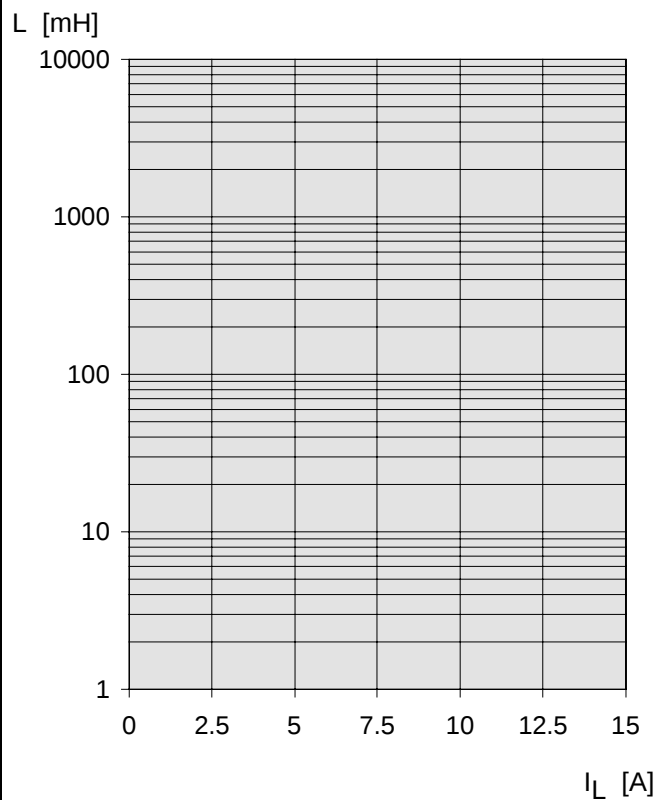
$$E_{AS} = E_{bb} + E_L - E_R = \int V_{ON(CL)} \cdot i_L(t) dt,$$

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

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

Maximum allowable load inductance for a single switch off

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



Options Overview

Type	BTS	660P	560
Overtemperature protection with hysteresis $T_j > 150\text{ °C}$, latch function ²¹⁾		X	X
$T_j > 150\text{ °C}$, with auto-restart on cooling		X	
Short circuit to GND protection switches off when $V_{ON} > 6\text{ V}$ typ. (when first turned on after approx. $180\text{ }\mu\text{s}$)		X	X
Overvoltage shutdown		-	-
Output negative voltage transient limit to $V_{bb} - V_{ON(CL)}$ to $V_{OUT} = -15\text{ V}$ typ		X X ²²⁾	X X ²²⁾

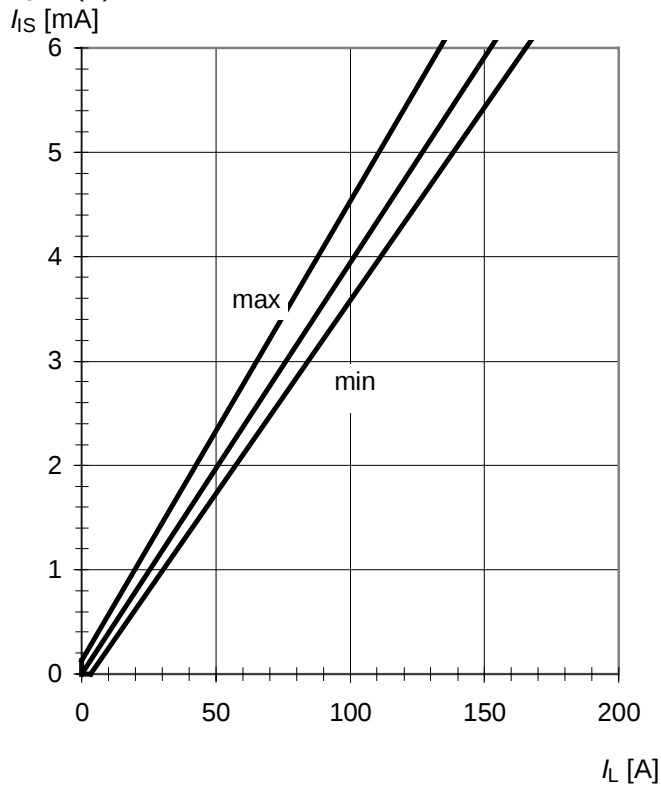
²¹⁾ Latch except when $V_{bb} - V_{OUT} < V_{ON(SC)}$ after shutdown. In most cases $V_{OUT} = 0\text{ V}$ after shutdown ($V_{OUT} \neq 0\text{ V}$ only if forced externally). So the device remains latched unless $V_{bb} < V_{ON(SC)}$ (see page 4). No latch between turn on and $t_{d(SC)}$.

²²⁾ Can be "switched off" by using a diode D_S (see page 7) or leaving open the current sense output.

Characteristics

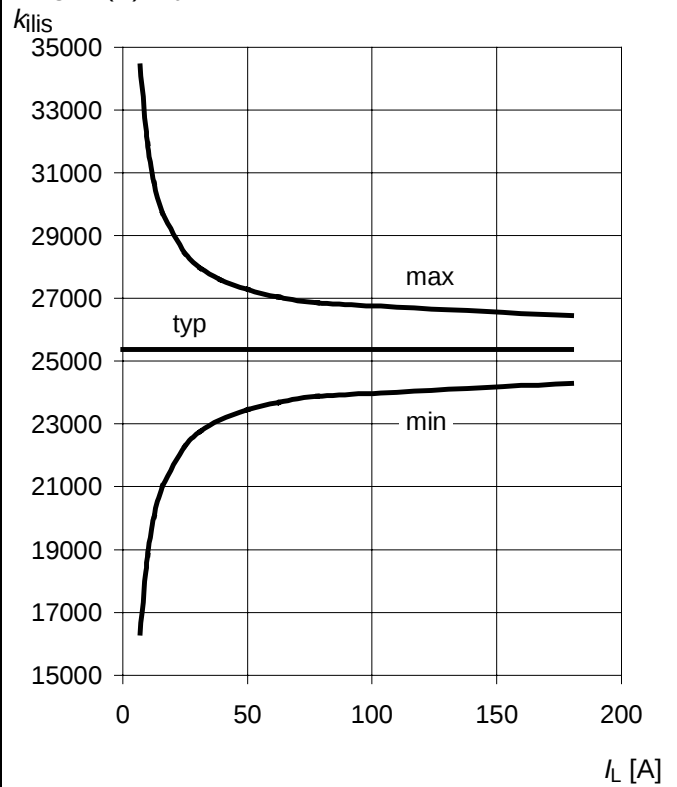
Current sense versus load current:

$$I_{IS} = f(I_L)$$



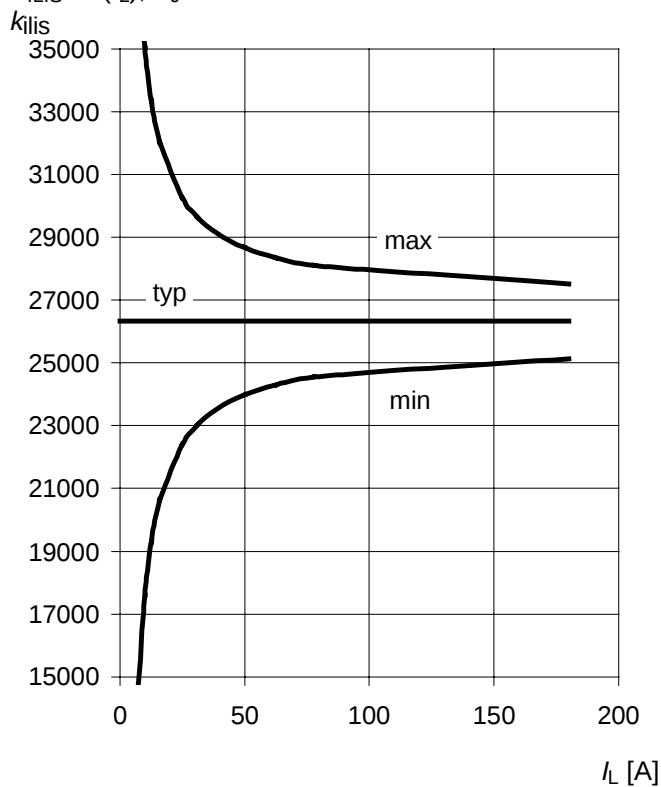
Current sense ratio:

$$K_{ILIS} = f(I_L), T_J = 25\text{ °C}$$



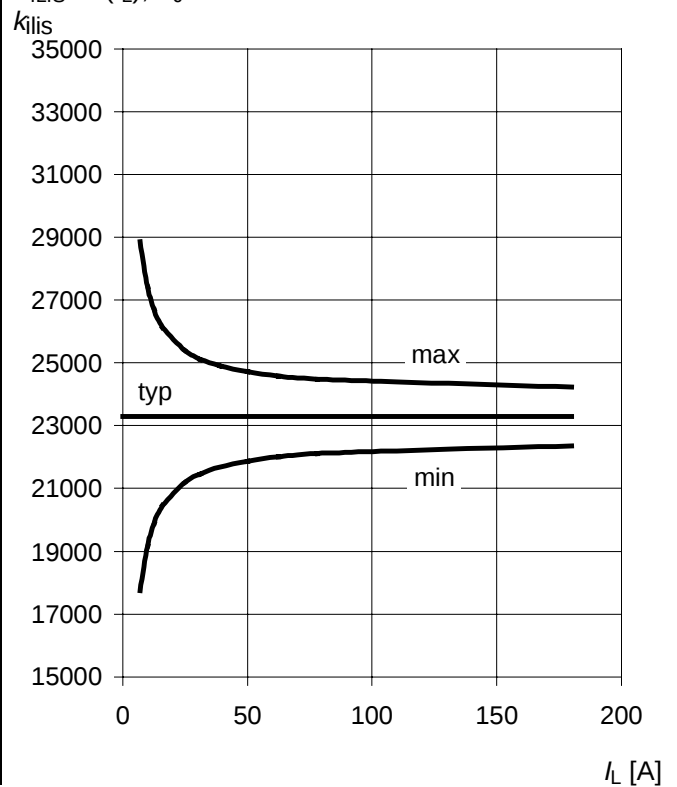
Current sense ratio:

$$K_{ILIS} = f(I_L), T_J = -40\text{ °C}$$



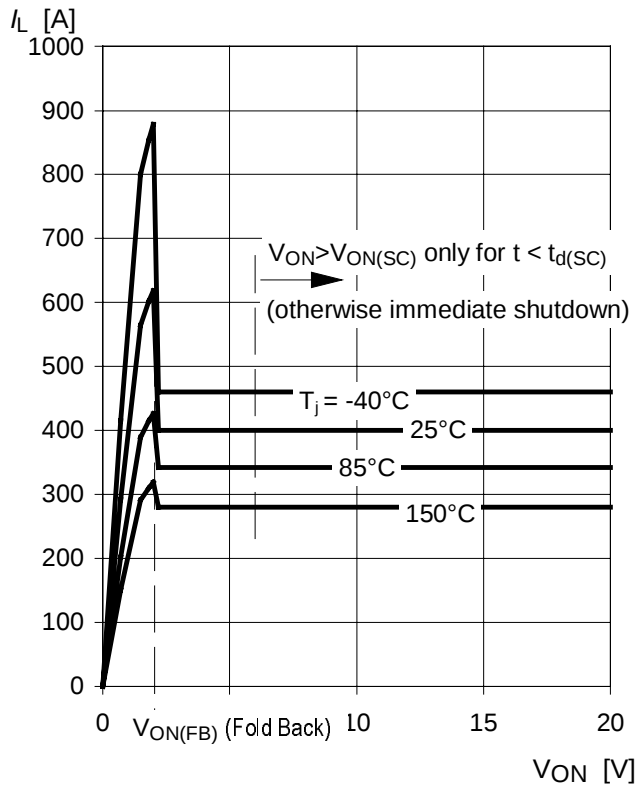
Current sense ratio:

$$K_{ILIS} = f(I_L), T_J = 150\text{ °C}$$



Typ. current limitation characteristic

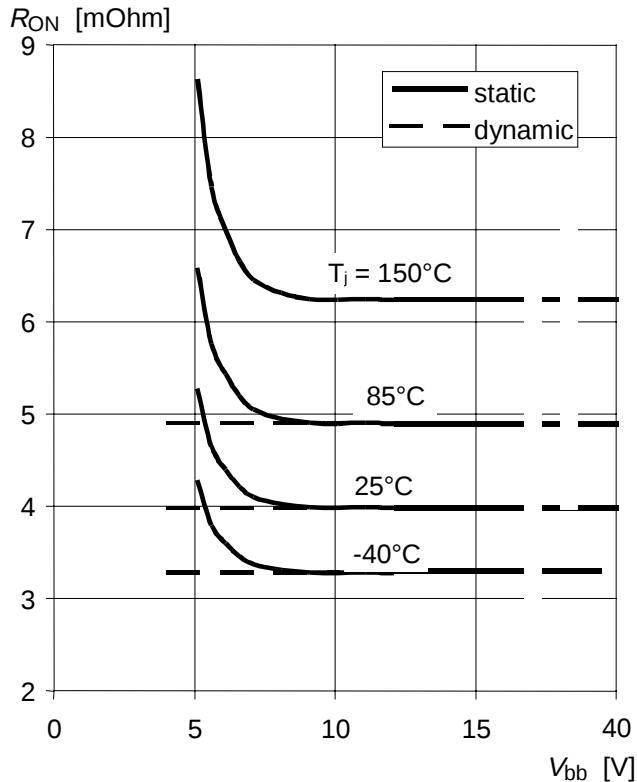
$$I_L = f(V_{ON}, T_j)$$



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

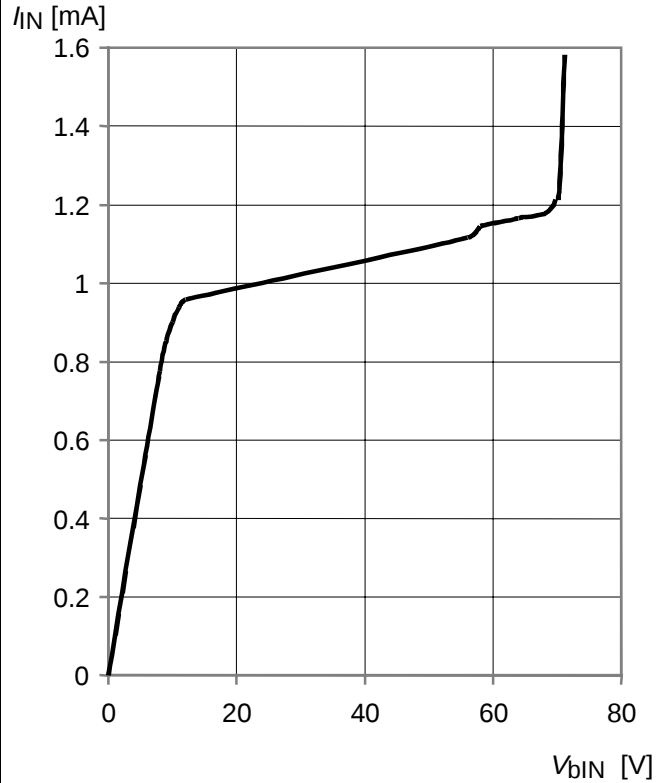
Typ. on-state resistance

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



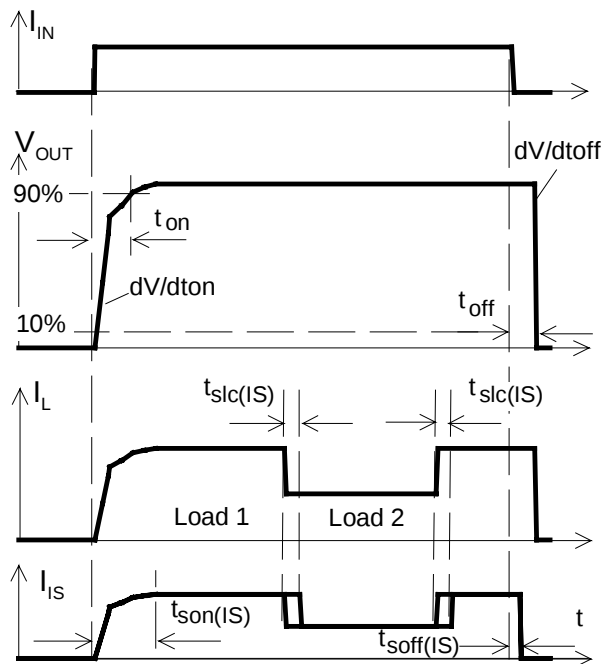
Typ. input current

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



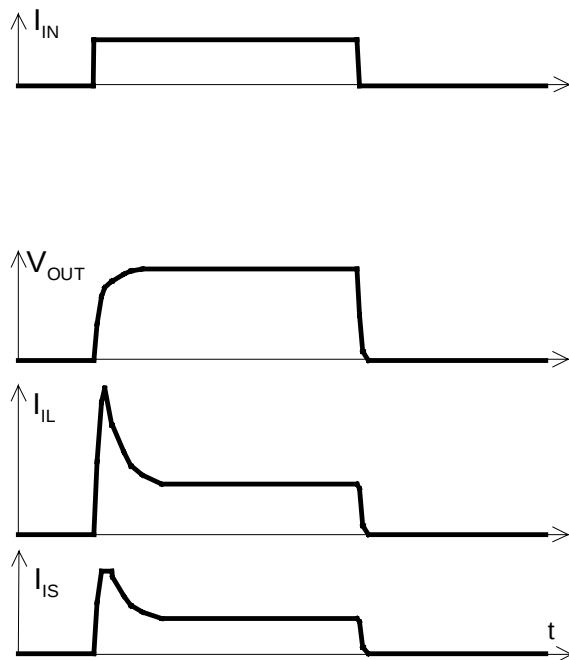
Timing diagrams

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 5).

Figure 2b: Switching an inductive load:

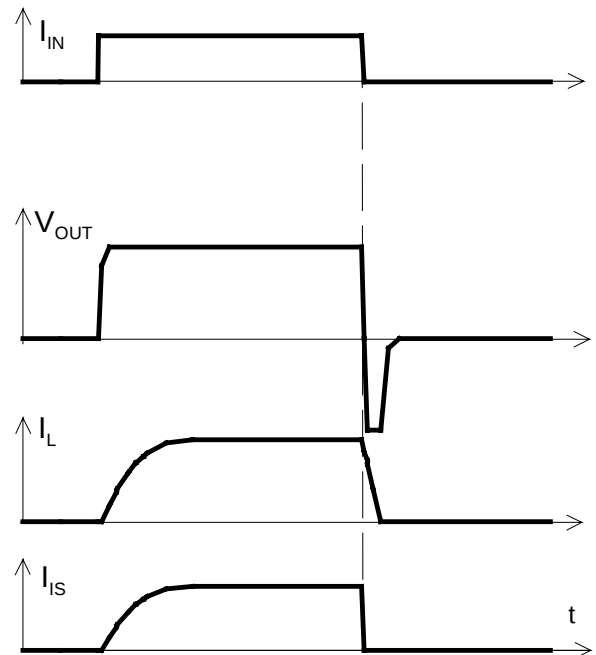
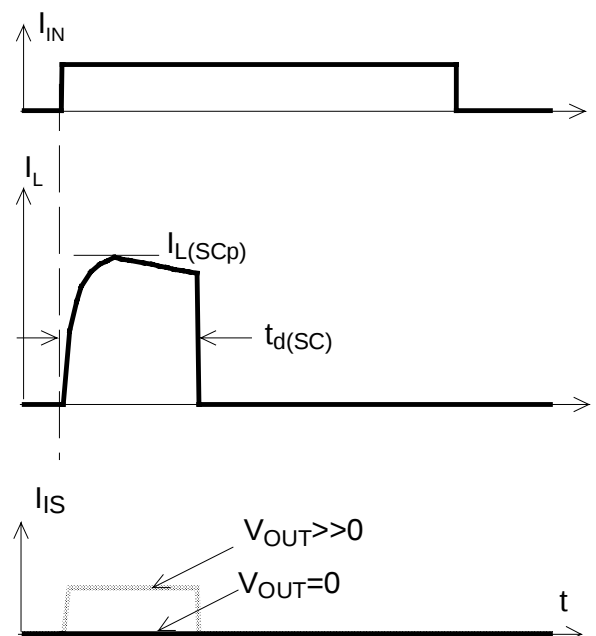


Figure 3a: Short circuit: shut down by short circuit detection, reset by $I_{IN} = 0$.



Shut down remains latched until next reset via input.

Figure 4a: Overtemperature,
Reset if ($I_{IN}=low$) and ($T_j < T_{jt}$)

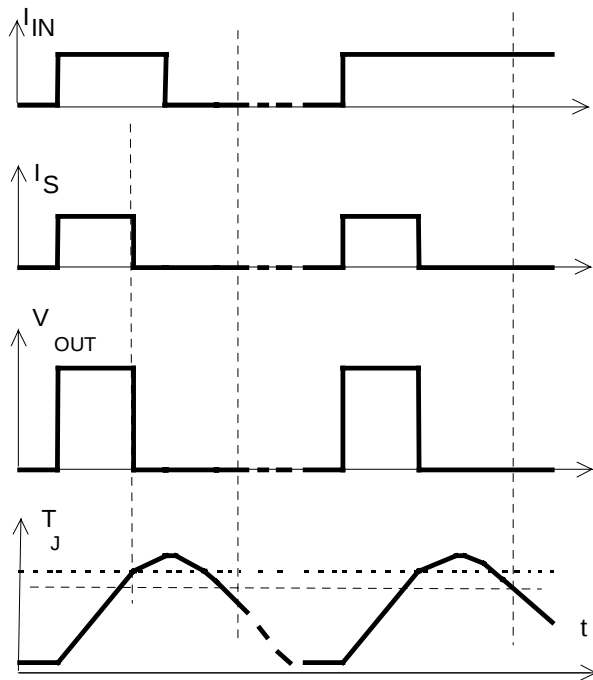
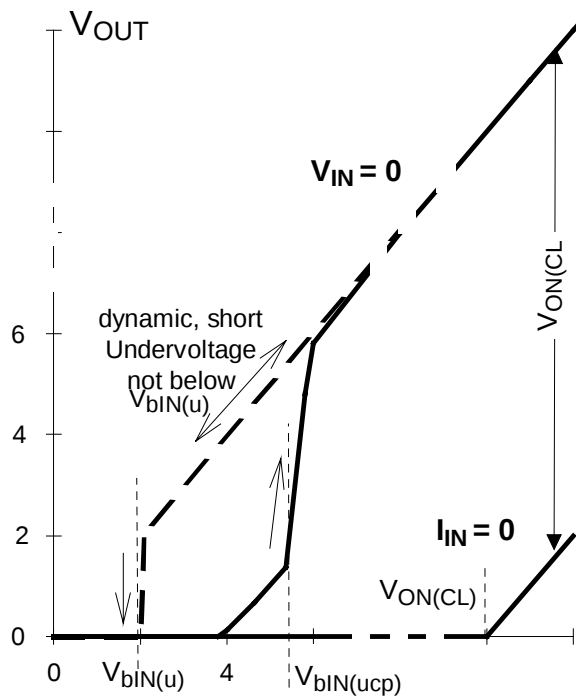


Figure 6a: Undervoltage restart of charge pump, overvoltage clamp

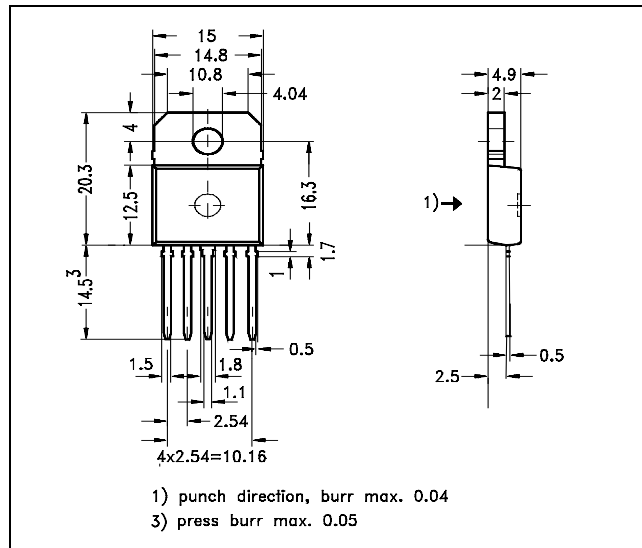


Package and Ordering Code

All dimensions in mm

TO-218AB/5 Option E3146 Ordering code

BTS560 E3146	Q67060-S6953A3
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