Smart Highside Power Switch

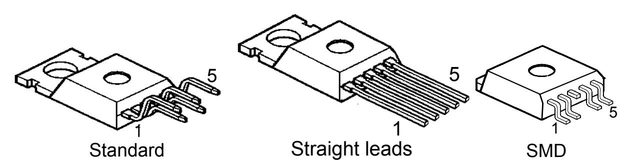
Features

- Overload protection
- Current limitation
- Short circuit protection
- Thermal shutdown
- Overvoltage protection (including load dump)
- Fast demagnetization of inductive loads
- Reverse battery protection[1)]
- Undervoltage and overvoltage shutdown with auto-restart and hysteresis
- Open drain diagnostic output
- Open load detection in ON-state
- CMOS compatible input
- Loss of ground and loss of V_{bb} protection
- **E**lectro**st**atic **d**ischarge (**ESD**) protection

Product Summary

Overvoltage protection	$V_{bb(AZ)}$	65	V
Operating voltage	$V_{bb(on)}$	4.7 ... 42	V
On-state resistance	R_{ON}	220	mΩ
Load current (ISO)	$I_{L(ISO)}$	1.8	A
Current limitation	$I_{L(SCr)}$	2.7	A

TO-220AB/5

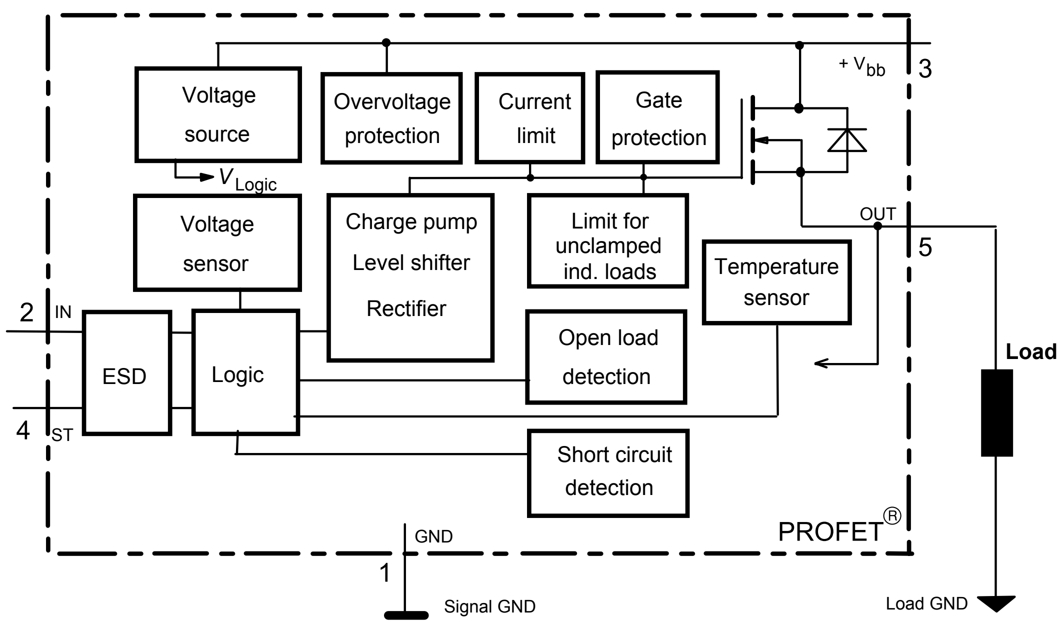


Application

- µC compatible power switch with diagnostic feedback for 12 V and 24 V DC grounded loads
- Most suitable for inductive loads
- Replaces electromechanical relays, fuses and discrete circuits

General Description

N channel vertical power FET with charge pump, ground referenced CMOS compatible input and diagnostic feedback, monolithically integrated in Smart SIPMOS® technology. Providing embedded protective functions.



1) With external current limit (e.g. resistor R_{GND}=150 Ω) in GND connection, resistors in series with IN and ST connections, reverse load current limited by connected load.

Pin	Symbol		Function
1	GND	-	Logic ground
2	IN	I	Input, activates the power switch in case of logical high signal
3	Vbb	+	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 °C unless otherwise specified

Parameter	Symbol	Values	Unit
Supply voltage (overvoltage protection see page 3)	V_{bb}	65	V
Load dump protection[2] $V_{LoadDump} = U_A + V_s$, U_A = 13.5 V R_I[3] = 2 Ω, R_L = 6.6 Ω, t_d = 400 ms, IN= low or high	$V_{Load\ dump}$[4]	100	V
Load current (Short circuit current, see page 4)	I_L	self-limited	A
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}	50	W
Inductive load switch-off energy dissipation, single pulse V_{bb} = 12V, $T_{j,start}$ = 150°C, T_C = 150°C const. I_L = 1.8 A, Z_L = 2.3 H, 0 Ω:	E_{AS}	4.5	J
Electrostatic discharge capability (ESD) IN: (Human Body Model) all other pins: acc. MIL-STD883D, method 3015.7 and ESD assn. std. S5.1-1993	V_{ESD}	1 2	kV
Input voltage (DC)	V_{IN}	-0.5 ... +6	V
Current through input pin (DC) Current through status pin (DC) see internal circuit diagrams page 6	I_{IN} I_{ST}	±5.0 ±5.0	mA

Thermal Characteristics

Parameter and Conditions	Symbol	Values			Unit
		min	typ	max	
Thermal resistance chip - case:	R_{thJC}	--	--	2.5	K/W
junction - ambient (free air):	R_{thJA}	--	--	75	
SMD version, device on PCB[5]:		--	35	--	

[2]) Supply voltages higher than $V_{bb(AZ)}$ require an external current limit for the GND and status pins, e.g. with a 150 Ω resistor in the GND connection and a 15 kΩ resistor in series with the status pin. A resistor for the protection of the input is integrated.

[3]) R_I = internal resistance of the load dump test pulse generator

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

[5]) 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.

Electrical Characteristics

Parameter and Conditions at T_j = 25 °C, V_{bb} = 12 V unless otherwise specified	Symbol	Values			Unit
		min	typ	max	
Load Switching Capabilities and Characteristics					
On-state resistance (pin 3 to 5) I_L = 1.6 A T_j=25 °C: T_j=150 °C:	R_{ON}	--	190 390	220 440	mΩ
Nominal load current, ISO Norm (pin 3 to 5) V_{ON} = 0.5 V, T_C = 85 °C	$I_{L(ISO)}$	1.6	1.8	--	A
Output current (pin 5) while GND disconnected or GND pulled up, V_{bb}=30 V, V_{IN}= 0, see diagram page 7, T_j =-40...+150°C	$I_{L(GNDhigh)}$	--	--	1	mA
Turn-on time IN ⌐ to 90% V_{OUT}: Turn-off time IN ¬ to 10% V_{OUT}: R_L = 12 Ω, T_j =-40...+150°C	t_{on} t_{off}	12 5	-- --	125 85	µs
Slew rate on 10 to 30% V_{OUT}, R_L = 12 Ω, T_j =-40...+150°C	dV/dt_{on}	--	--	3	V/µs
Slew rate off 70 to 40% V_{OUT}, R_L = 12 Ω, T_j =-40...+150°C	$-dV/dt_{off}$	--	--	6	V/µs

Operating Parameters

Operating voltage [6] T_j =-40...+150°C:	$V_{bb(on)}$	4.7	--	42	V
Undervoltage shutdown T_j =25°C: T_j =-40...+150°C:	$V_{bb(under)}$	2.9 2.7	-- --	4.5 4.7	V
Undervoltage restart T_j =-40...+150°C:	$V_{bb(u\,rst)}$	--	--	4.9	V
Undervoltage restart of charge pump see diagram page 13	$V_{bb(ucp)}$	--	5.6	6.0	V
Undervoltage hysteresis $\Delta V_{bb(under)} = V_{bb(u\,rst)} - V_{bb(under)}$	$\Delta V_{bb(under)}$	--	0.1	--	V
Overvoltage shutdown T_j =-40...+150°C:	$V_{bb(over)}$	42	--	52	V
Overvoltage restart T_j =-40...+150°C:	$V_{bb(o\,rst)}$	40	--	--	V
Overvoltage hysteresis T_j =-40...+150°C:	$\Delta V_{bb(over)}$	--	0.1	--	V
Overvoltage protection[7] T_j =-40...+150°C: I_{bb}=4 mA	$V_{bb(AZ)}$	65	70	--	V
Standby current (pin 3) T_j=-40...+25°C: V_{IN}=0 T_j= 150°C:	$I_{bb(off)}$	-- --	10 18	15 25	µA
Leakage output current (included in $I_{bb(off)}$) V_{IN}=0	$I_{L(off)}$	--	--	20	µA
Operating current (Pin 1)[8], V_{IN}=5 V, T_j =-40...+150°C	I_{GND}	--	1	2.1	mA

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

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

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

Parameter and Conditions at T_j = 25 °C, V_{bb} = 12 V unless otherwise specified	Symbol	Values min	Values typ	Values max	Unit
Protection Functions[9]					
Initial peak short circuit current limit (pin 3 to 5)[10], (max 450 µs if $V_{ON} > V_{ON(SC)}$)	$I_{L(SCp)}$				
T_j =-40°C: T_j =25°C: T_j =+150°C:		4.0 3.5 2.0	-- 5.5 3.5	11 10 7.5	A
Overload shutdown current limit	$I_{L(SCr)}$				
V_{ON}= 8 V, $T_j = T_{jt}$ (see timing diagrams, page 11)		--	2.7	--	A
Short circuit shutdown delay after input pos. slope $V_{ON} > V_{ON(SC)}$, T_j =-40..+150°C: min value valid only, if input "low" time exceeds 60 µs	$t_{d(SC)}$	--	--	450	µs
Output clamp (inductive load switch off) at $V_{OUT} = V_{bb} - V_{ON(CL)}$ I_L= 40 mA, T_j =-40..+150°C:	$V_{ON(CL)}$	61	68	73	V
I_L= 1 A, T_j =-40..+150°C:		--	--	75	
Short circuit shutdown detection voltage(pin 3 to 5)	$V_{ON(SC)}$	--	8.5	--	V
Thermal overload trip temperature	T_{jt}	150	--	--	°C
Thermal hysteresis	ΔT_{jt}	--	10	--	K
Reverse battery (pin 3 to 1) [11]	$-V_{bb}$	--	--	32	V

Diagnostic Characteristics

Open load detection current (on-condition) T_j=-40 ..150°C:	$I_{L\ (OL)}$	2	--	150	mA

[9]) Integrated protection functions are designed to prevent IC destruction under fault conditions described in the data sheet. Fault conditions are considered as “outside” normal operating range. Protection functions are not designed for continuous repetitive operation.

[10]) Short circuit current limit for max. duration of $t_{d(SC)\ max}$=450 µs, prior to shutdown

[11]) Requires 150 Ω resistor in GND connection. The reverse load current through the intrinsic drain-source diode has to be limited by the connected load. Note that the power dissipation is higher compared to normal operating conditions due to the voltage drop across the intrinsic drain-source diode. The temperature protection is not active during reverse current operation! Input and Status currents have to be limited (see max. ratings page 2 and circuit page 7).

Parameter and Conditions at T_j = 25 °C, V_{bb} = 12 V unless otherwise specified	Symbol	Values min	typ	max	Unit
Input and Status Feedback[12]					
Input turn-on threshold voltage T_j =-40..+150	$V_{IN(T+)}$	1.5	--	2.4	V
Input turn-off threshold voltage T_j =-40..+150°	$V_{IN(T-)}$	1.0	--	--	V
Input threshold hysteresis	$\Delta V_{IN(T)}$	--	0.5	--	V
Off state input current (pin 2), V_{IN} = 0.4 V	$I_{IN(off)}$	1	--	30	µA
On state input current (pin 2), V_{IN} = 5 V	$I_{IN(on)}$	10	25	70	µA
Status invalid after positive input slope (short circuit) T_j=-40 ... +150°C:	$t_{d(ST\ SC)}$	--	--	450	µs
Status invalid after positive input slope (open load) T_j=-40 ... +150°C:	$t_{d(ST)}$	300	--	1400	µs
Status output (open drain)					
Zener limit voltage T_j =-40...+150°C, I_{ST} = +50 uA: ST low voltage T_j =-40...+150°C, I_{ST} = +1.6 mA:	$V_{ST(high)}$ $V_{ST(low)}$	5.0 --	6 --	-- 0.4	V

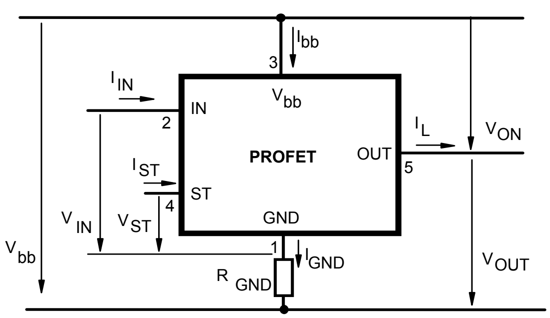
[12]) If a ground resistor R_{GND} is used, add the voltage drop across this resistor.

Truth Table

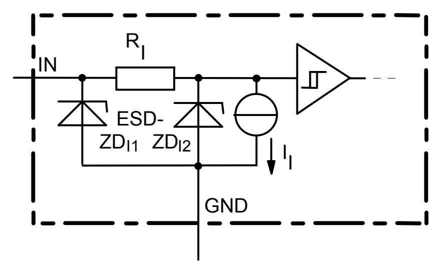
	Input-level	Output level	Status				
			412 B2	410 D2	**410** E2/**F2**	410 G2	410 H2
Normal operation	**L**	**L**	H	H	**H**	H	H
	H	**H**	H	H	**H**	H	H
Open load	**L**	[13]	L	H	**H**	H	L
	H	**H**	H	L	**L**	L	H
Short circuit to GND	**L**	**L**	H	H	**H**	H	H
	H	**L**	L	L	**L**	H	L
Short circuit to V_{bb}	**L**	**H**	L	H	**H**	H	L
	H	**H**	H	H (L[14])	**H (L[14])**	H (L[14])	H
Overtem-perature	**L**	**L**	L	L	**L**	L	L
	H	**L**	L	L	**L**	L	L
Under-voltage	**L**	**L**	L[15]	L[15]	**H**	H	H
	H	**L**	L[15]	L[15]	**H**	H	H
Overvoltage	**L**	**L**	L	L	**H**	H	H
	H	**L**	L	L	**H**	H	H

L = "Low" Level   X = don't care   Z = high impedance, potential depends on external circuit
H = "High" Level   Status signal after the time delay shown in the diagrams (see fig 5. page 12...13)

Terms



Input circuit (ESD protection)



ZD_{I1} 6 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).

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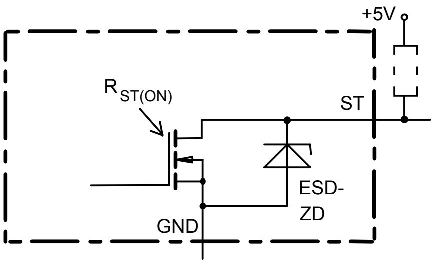
13) Power Transistor off, high impedance, versions BTS 410H, BTS 412B: internal pull up current source for open load detection.
14) Low resistance short V_{bb} to output may be detected in ON-state by the no-load-detection
15) No current sink capability during undervoltage shutdown

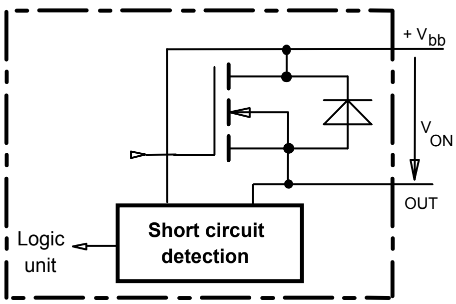
Status output



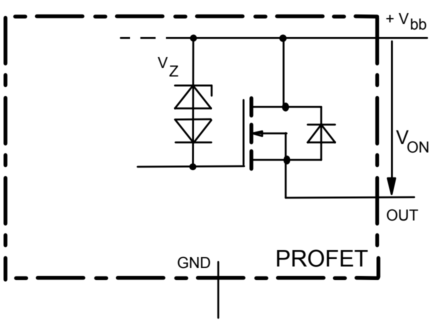
ESD-Zener diode: 6 V typ., max 5 mA;
$R_{ST(ON)}$ < 250 Ω at 1.6 mA, ESD zener diodes are not to be used as voltage clamp at DC conditions. Operation in this mode may result in a drift of the zener voltage (increase of up to 1 V).

Short circuit detection

Fault Condition: V_{ON} > 8.5 V typ.; IN high

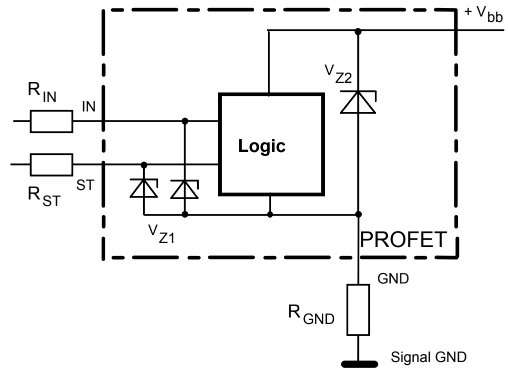


Inductive and overvoltage output clamp



V_{ON} clamped to 68 V typ.

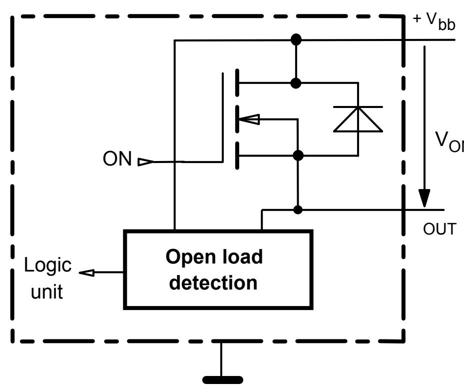
Overvolt. and reverse batt. protection



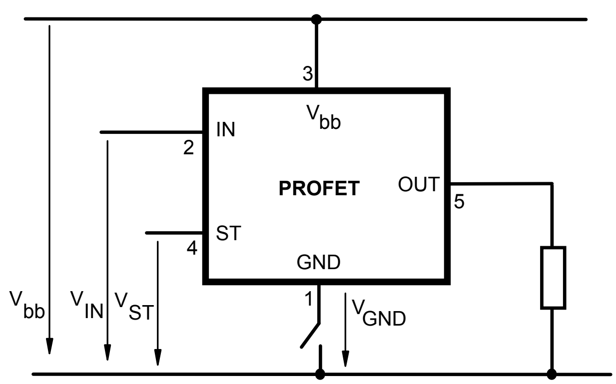
V_{Z1} = 6.2 V typ., V_{Z2} = 70 V typ., R_{GND}= 150 Ω, R_{IN}, R_{ST}= 15 kΩ

Open-load detection

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

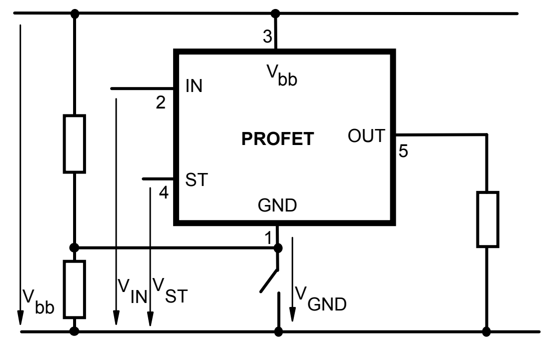


GND disconnect



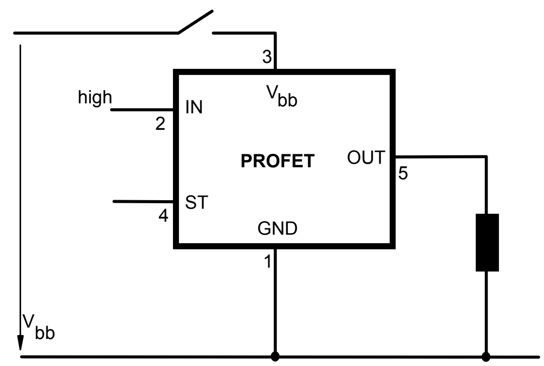
Any kind of load. In case of Input=high is $V_{OUT} \approx V_{IN} - V_{IN(T+)}$.
Due to V_{GND} >0, no V_{ST} = low signal available.

GND disconnect with GND pull up



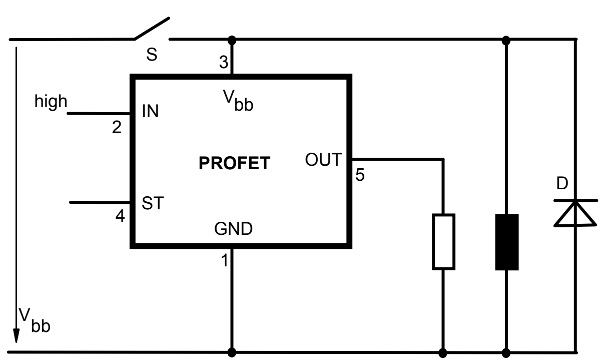
Any kind of load. If $V_{GND} > V_{IN} - V_{IN(T+)}$ device stays off
Due to V_{GND} >0, no V_{ST} = low signal available.

V_{bb} disconnect with energized inductive load



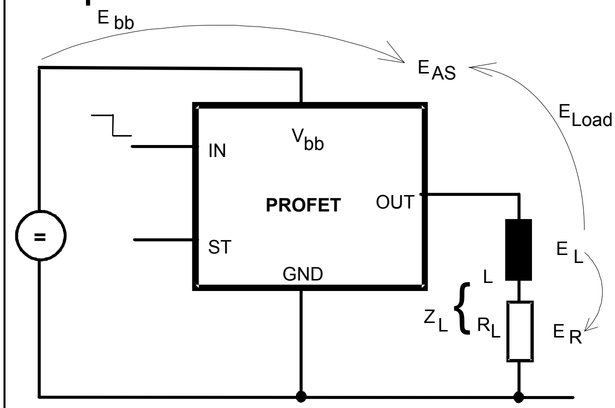
Normal load current can be handled by the PROFET itself.

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:

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

While demagnetizing load inductance, the energy dissipated in PROFET is

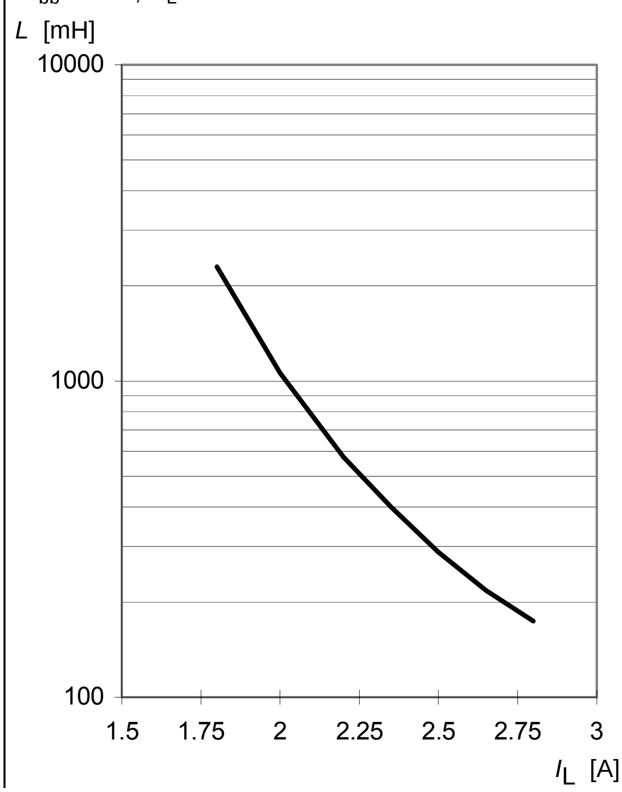
$$E_{AS} = E_{bb} + E_L - E_R = \quad V_{ON(CL)} \cdot i_L(t)\,dt,$$

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

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

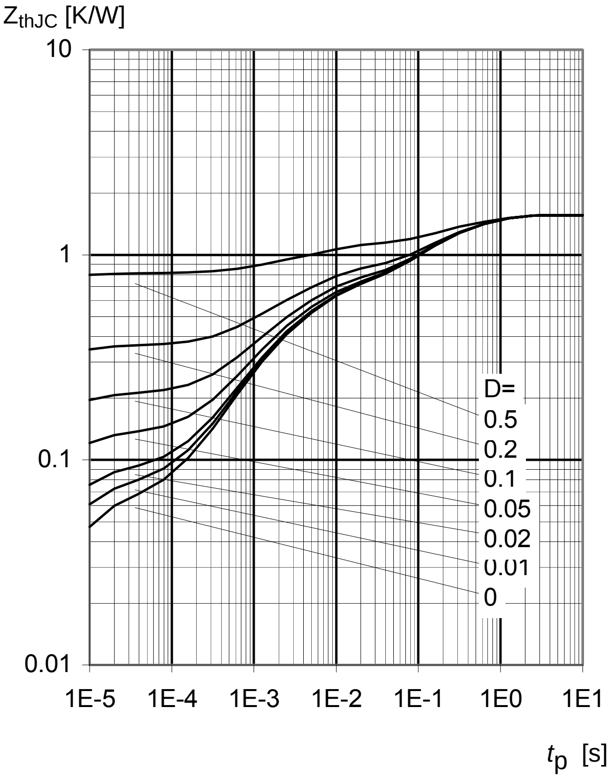
Maximum allowable load inductance for a single switch off

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



Typ. transient thermal impedance chip case

$Z_{thJC} = f(t_p, D)$, $D = t_p/T$



Options Overview

all versions: High-side switch, Input protection, ESD protection, load dump and reverse battery protection with 150 Ω in GND connection, protection against loss of ground

Type BTS	412 B2	410D2	410E2	**410F2**	410G2	410H2	307	308
Logic version	B	D	E	**F**	G	H		
Overtemperature protection with hysteresis								
T_j >150 °C, latch function[16][17]	X	X		**X**		X		X
T_j >150 °C, with auto-restart on cooling			X		X		X	
Short circuit to GND protection								
switches off when V_{ON}>3.5 V typ. and V_{bb}> 7 V typ[16] (when first turned on after approx. 150 µs)						X		X
switches off when V_{ON}>8.5 V typ.[16] (when first turned on after approx. 150 µs)	X	X	X	**X**				
Achieved through overtemperature protection					X		X	
Open load detection								
in OFF-state with sensing current 30 µA typ.	X					X	X	X
in ON-state with sensing voltage drop across power transistor		X	X	**X**	X			
Undervoltage shutdown with auto restart	X	X	X	**X**	X	X	X	X
Overvoltage shutdown with auto restart[18]	X	X	X	**X**	X	X	-	X
Status feedback for								
overtemperature	X	X	X	**X**	X	X	X	X
short circuit to GND	X	X	X	**X**	-	X	X	X
short to V_{bb}	X	-[19]	-[19]	**-[19]**	-[19]	X	X	X
open load	X	X	X	**X**	X	X	X	X
undervoltage	X	X	-	**-**	-	-	X	-
overvoltage	X	X	-	**-**	-	-	-	-
Status output type								
CMOS	X	X						
Open drain			X	**X**	X	X	X	X
Output negative voltage transient limit (fast inductive load switch off)								
to V_{bb} - $V_{ON(CL)}$	X	X	X	**X**	X	X	X	X
Load current limit								
high level (can handle loads with high inrush currents)	X	X	X					
low level (better protection of application)				**X**	X	X	X	X
Protection against loss of GND	X	X	X	**X**	X	X	X	X

[16] 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 4). No latch between turn on and $t_{d(SC)}$.

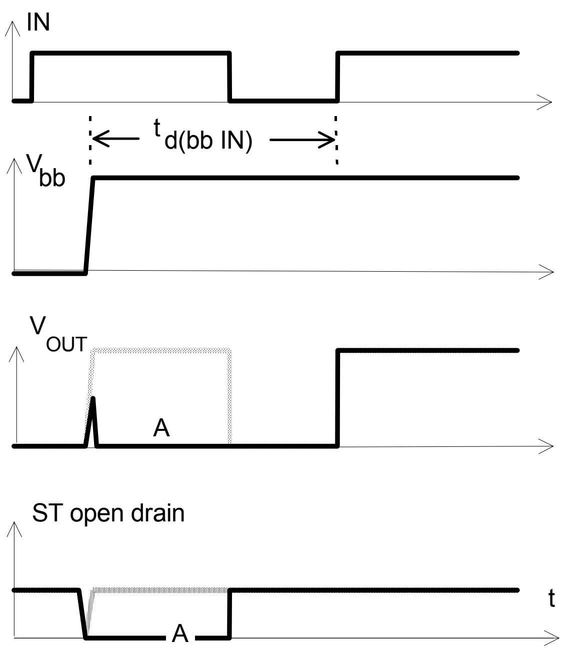
[17] With latch function. Reseted by a) Input low, b) Undervoltage

[18] No auto restart after overvoltage in case of short circuit

[19] Low resistance short V_{bb} to output may be detected in ON-state by the no-load-detection

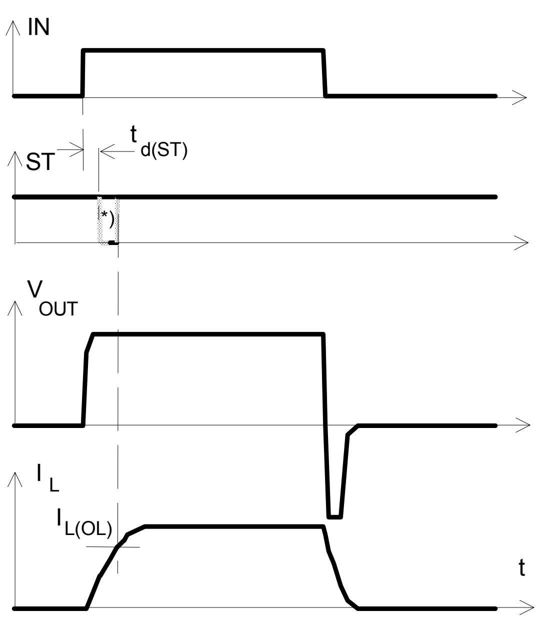
Timing diagrams

Figure 1a: V_{bb} turn on:



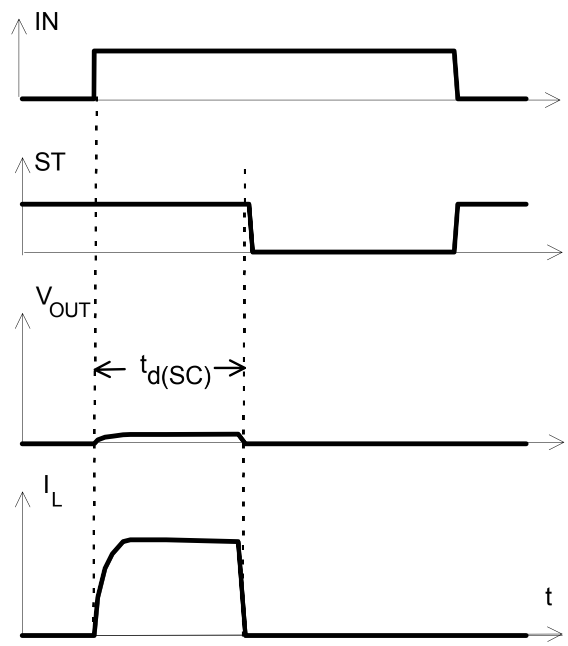
in case of too early V_{IN}=high the device may not turn on (curve A)
$t_{d(bb\ IN)}$ approx. 150 µs

Figure 2a: Switching an inductive load



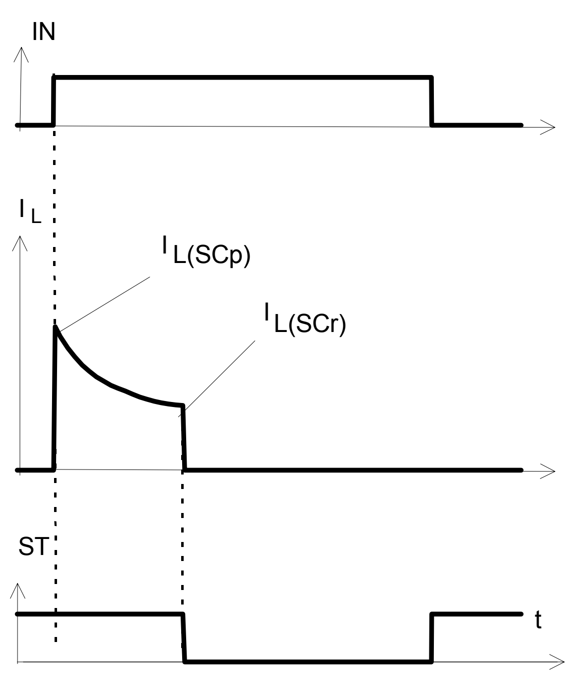
*) if the time constant of load is too large, open-load-status may occur

Figure 3a: Turn on into short circuit,



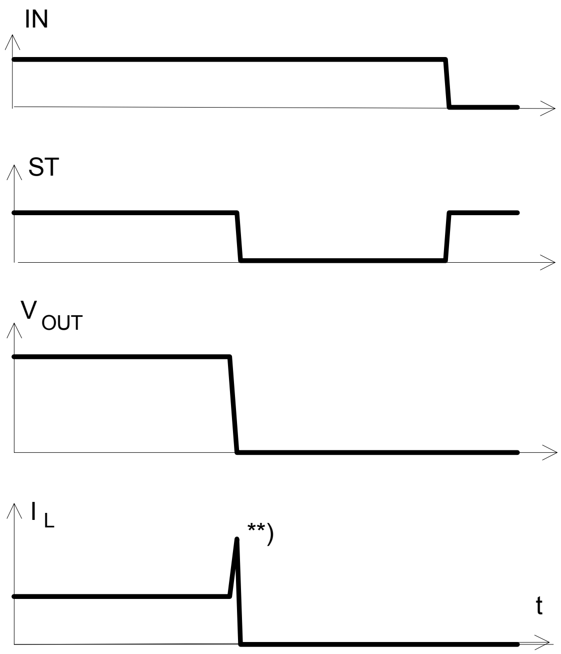
$t_{d(SC)}$ approx. -- µs if V_{bb} - V_{OUT} > 8.5 V typ.

Figure 3b: Turn on into overload,



Heating up may require several seconds,
V_{bb} - V_{OUT} < 8.5 V typ.

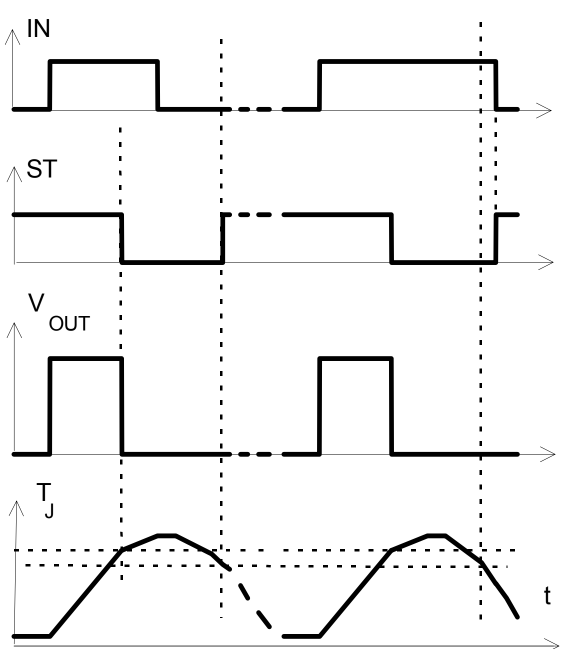
Figure 3c: Short circuit while on:



**) current peak approx. 20 µs

Figure 4a: Overtemperature,

Reset if (IN=low) and (T_j<T_{jt})



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

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

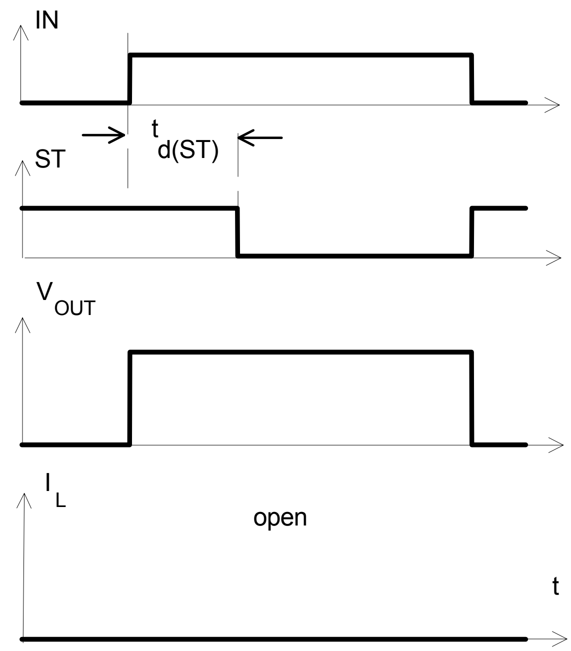
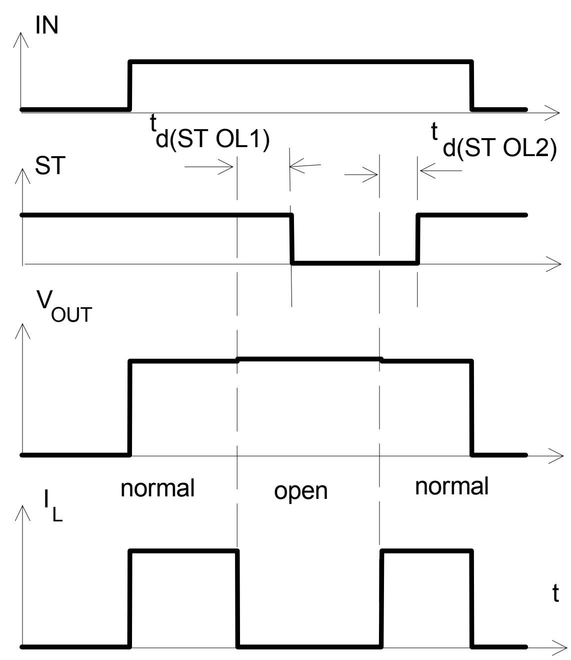


Figure 5b: Open load: detection in ON-state, open load occurs in on-state



$t_{d(ST\ OL1)}$ = tbd µs typ., $t_{d(ST\ OL2)}$ = tbd µs typ

Figure 6a: Undervoltage:

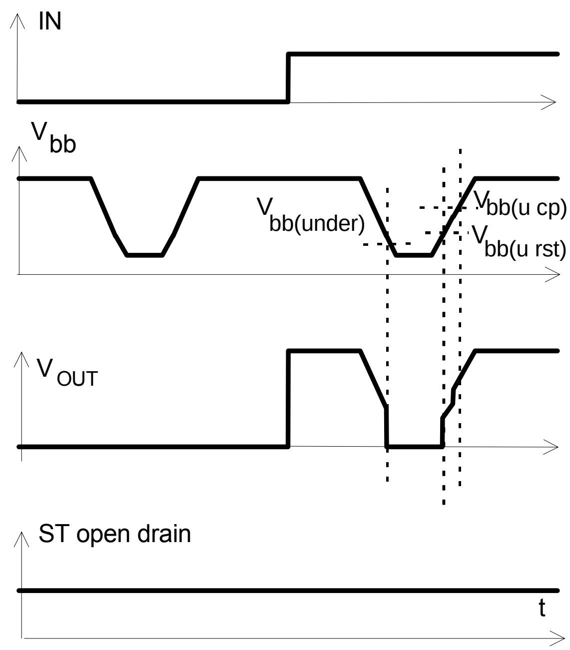


Figure 7a: Overvoltage:

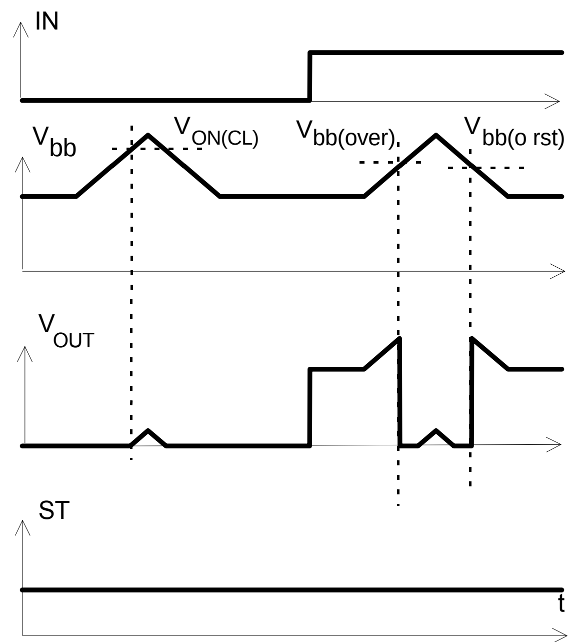
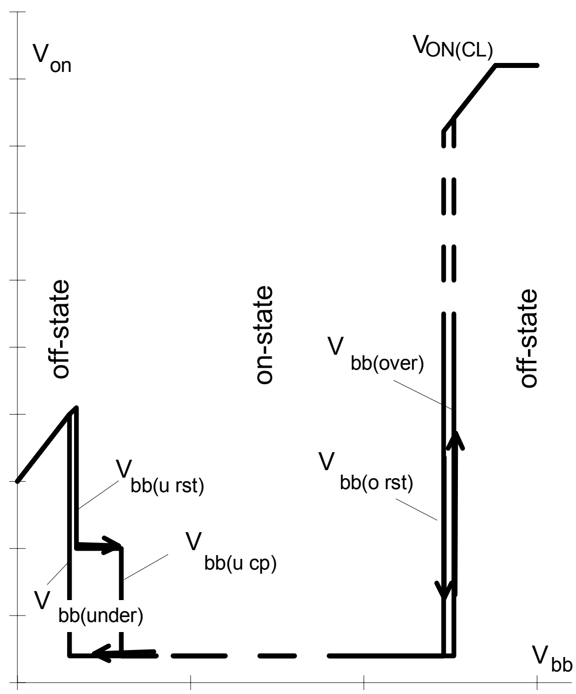
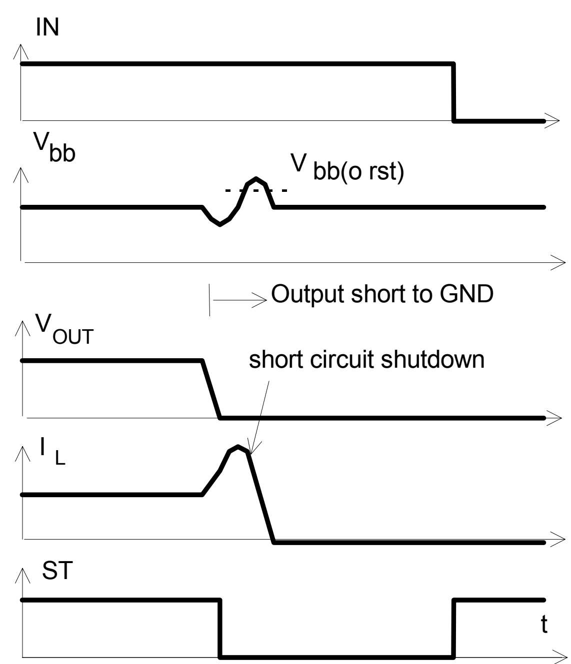


Figure 6b: Undervoltage restart of charge pump



charge pump starts at $V_{bb(ucp)}$ =5.6 V typ.

Figure 9a: Overvoltage at short circuit shutdown:



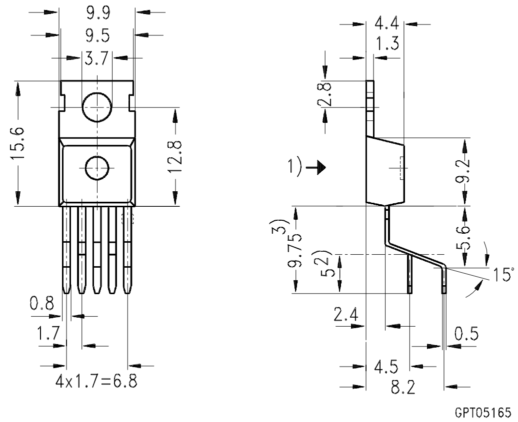
Overvoltage due to power line inductance. No overvoltage auto-restart of PROFET after short circuit shutdown.

Package and Ordering Code

All dimensions in mm

Standard TO-220AB/5 Ordering code

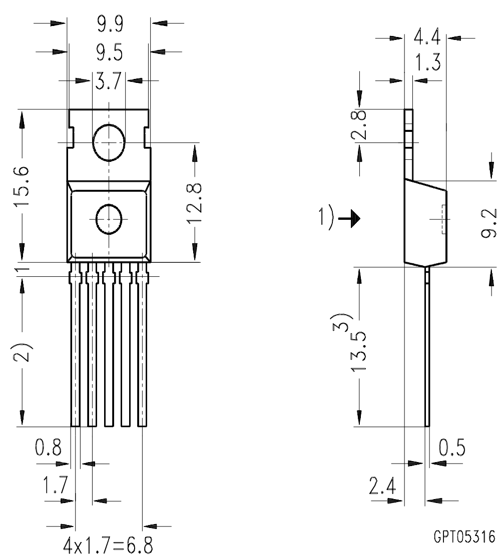
BTS 410 F2		Q67060-S6103-A2



1) shear and punch direction no burrs this surface
2) min. length by tinning
3) max. 11 mm allowable by tinning

TO-220AB/5, Option E3043 Ordering code

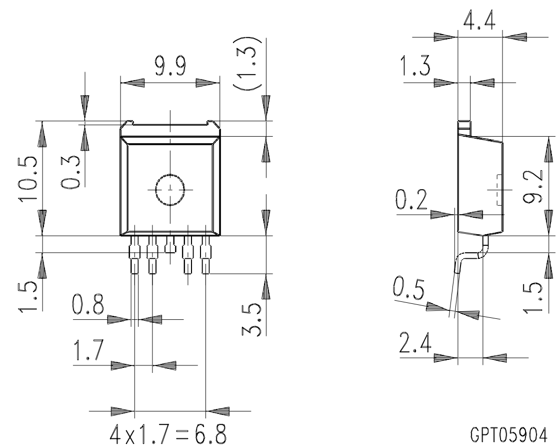
BTS 410 F2 E3043		Q67060-S6103-A3



1) punch direction, burr max. 0.04
2) dip tinning
3) max. 14.5 by dip tinning press burr max. 0.05

SMD TO-220AB/5, Opt. E3062 Ordering code

BTS410F2 E3062A	T&R:	Q67060-S6103-A4



Changed since 04.96	
Date	Change
Mar. 1997	E_{AS} maximum rating and diagram and Z_{thJC} diagram added
	ESD capability (except Input) specified to 2kV, R_{thJA} SMD specified
	$I_{L(GND\ high)\ max}$ reduced from 10 to 1 mA
	Option Overview table columns for BTS307/308 added
	Fig. 1a: V_{out}-spike at V_{bb}-turn-on added

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