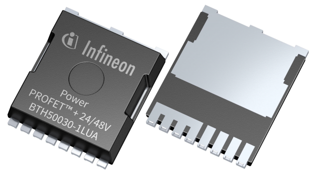
BTH50030-1LUA

Datasheet

Power PROFET™ + 24/48V smart high-side power switch

Features

- PRO-SIL™ ISO 26262-ready for supporting the integrator in evaluation of hardware element according to ISO 26262:2018 Clause 8-13
- One channel device
- Low stand-by current
- Ground loss protection
- Electrostatic discharge protection (ESD)
- Optimized electromagnetic compatibility (EMC)
- Integrated diagnostic functions
- Integrated protection functions
- Green product (RoHS compliant)



AEC Qualified

RoHS

ISO 26262 ready

Halogen-free

Potential applications

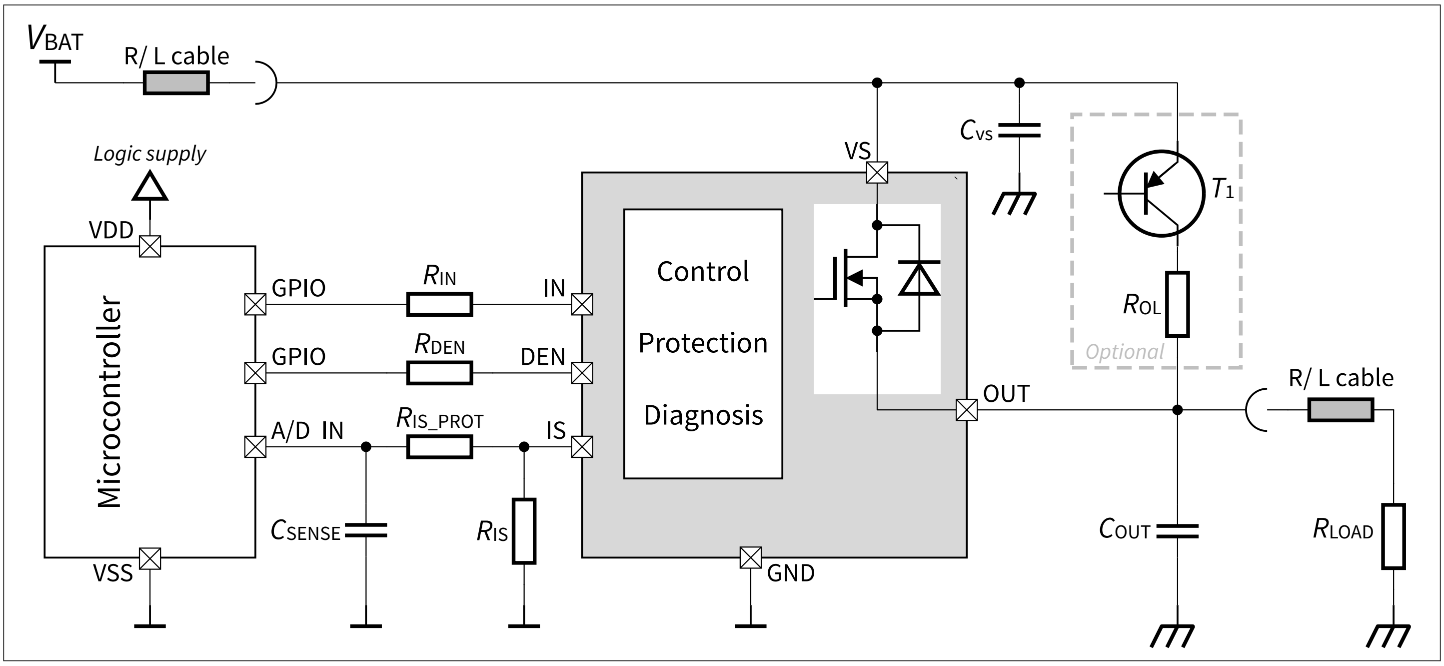
- Suitable for resistive, inductive and capacitive loads
- Replaces electromechanical relays, fuses and discrete circuits
- Most suitable for application with high current loads, such as heating system, fan and pump
- PWM applications with low frequency

Product validation

Qualified for Automotive Applications. Product Validation according to AEC-Q100 grade 1.

Description

The device is a 3.0 mΩ single channel smart high-side power switch, available in a PG-HSOF-8 package, providing protective functions and diagnosis. It is especially designed to drive high current loads, for applications like heaters, glow plugs, fans and pumps.



Application diagram

Type	Package	Marking
BTH50030-1LUA	PG-HSOF-8	H50030A

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1 Product description

1.1 Product summary

Table 1 Product summary

Parameter	Symbol	Values
Operating voltage	$V_{S(NOM)}$	12 V … 54 V
Extended supply voltage range	$V_{S(EXT)}$	8 V … 60 V
Maximum on-state resistance (T_J = 150 °C)	$R_{DS(ON)}$	7.0 mΩ
Minimum nominal load current (T_A = 85°C, 4-layer 2s2p PCB)	$I_{L(NOM)}$	22.5 A
Typical current sense ratio	dk_{ILIS}	34000
Minimum short circuit current threshold	$I_{CL(0)}$	55 A
Maximum stand-by current at T_J = 25 °C	$I_{VS(OFF\_L)}$	7 µA

1.2 Integrated diagnosis and protection functions

Integrated diagnosis functions

- Proportional load current sense
- Open load detection in on and off state
- Diagnosis enable pin
- Latched status signal after short circuit or overtemperature detection

Integrated protection functions

- Short circuit protection with latch
- Overtemperature protection with latch
- Enhanced short circuit operation
- Smart clamping for inductive loads demagnetization

2 Block diagram

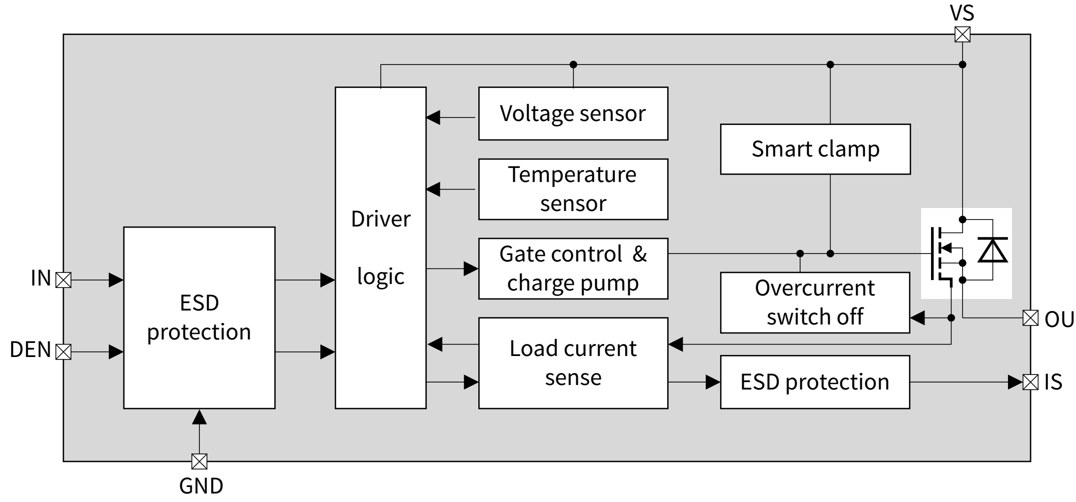


Figure 2 **Block diagram**

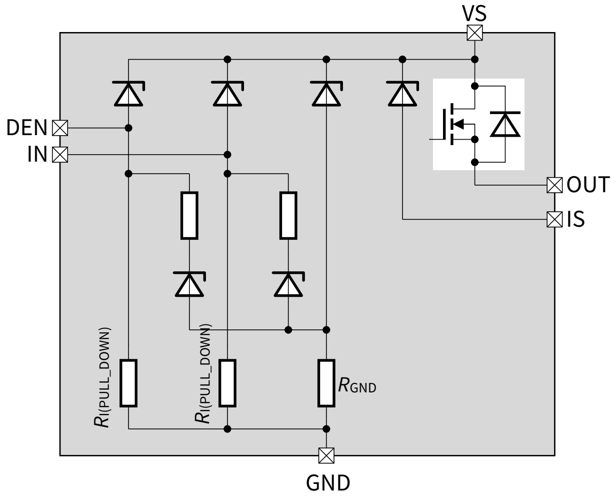


Figure 3 **Internal diodes diagram**

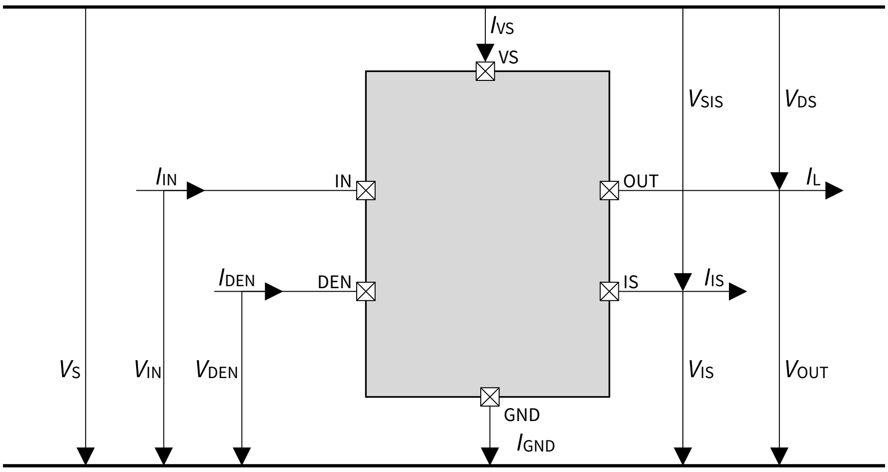


Figure 4 **Voltage and current definition**

3 Pin configuration

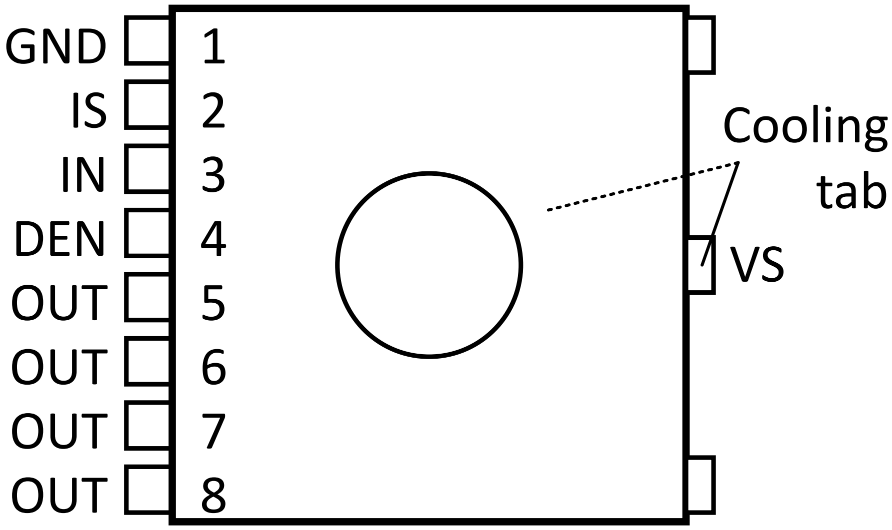


Figure 5 **Pin assignment**

Table 2 **Pin definitions and function**

Pin	Symbol	Function
1	GND	Ground pin
2	IS	Sense pin: analog/digital signal for diagnosis, if not used: left open
3	IN	Input pin: digital signal to switch on the output (active high)
4	DEN	Diagnosis enable pin: digital signal to enable the diagnosis (active high)
5, 6, 7, 8	OUT	Output pin: single protected high side power output
Cooling tab	VS	Supply voltage: battery voltage

4 General product characteristics

4.1 Absolute maximum ratings

Table 3 **Absolute maximum ratings**

T_J = -40°C to +150°C; all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	P-Number
		Min.	Typ.	Max.			
Supply voltages							
Supply voltage	V_S	-0.3	–	70	V	[1]	PRQ-32
Short term overvoltage	$V_{S(STO)}$	–	–	70	V	[1] Short term overvoltage according to ISO 21780:2020(E), test-03 $R_L = R_{L(NOM)}$ R_{IS} = 2 kΩ	PRQ-34
Short circuit capability							
Supply voltage for short circuit protection	$V_{S(SC)}$	8	–	36	V	[1] According to the test circuit defined in figure 1 of AEC Q100-012, with L_{SUPPLY} = 1 to 15 µH and L_{SHORT} = 0 to 15 µH	PRQ-381
Supply voltage for short circuit protection	$V_{S(SC)}$	36	–	54	V	[1] According to the test circuit defined in figure 1 of AEC Q100-012, with L_{SUPPLY} = 1 to 5 µH and L_{SHORT} = 0 to 5 µH	PRQ-384
Supply voltage for short circuit protection	$V_{S(SC)}$	54	–	60	V	[1] According to the test circuit defined in figure 1 of AEC Q100-012, with $L_{SUPPLY} + L_{SHORT}$ = 1 to 5 µH	PRQ-35
Input pin (IN)							
Voltage at IN pin	V_{IN}	V_S - 75	–	V_S + 0.3	V	[1]	PRQ-36
Current through IN pin	I_{IN}	-50	–	50	mA	[1]	PRQ-37
Maximum input frequency	f_{IN}	–	–	100	Hz	[1] V_S in $V_{S(EXT)}$ range	PRQ-38
Maximum retry cycle rate in fault condition	f_{FAULT}	–	–	100	Hz	[1]	PRQ-39
Diagnosis enable pin (DEN)							
Voltage at DEN pin	V_{DEN}	V_S - 75	–	V_S + 0.3	V	[1]	PRQ-40

(table continues...)

Table 3 (continued) Absolute maximum ratings

T_J = -40°C to +150°C; all voltages with respect to ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or condition	P-Number
		Min.	Typ.	Max.			
Current through DEN pin	I_{DEN}	-50	–	50	mA	[1]	PRQ-41
Sense and diagnosis pin (IS)							
Voltage at IS pin	V_{IS}	V_S - 75	–	V_S + 0.3	V	[1]	PRQ-42
Current through IS pin	I_{IS}	-50	–	50	mA	[1]	PRQ-43
Power stage							
Maximum energy dissipation by switching off inductive load single pulse over lifetime	E_{AS}	–	–	175	mJ	[1] I_L = 17 A, $T_{J(0)} \leq 150°C$	PRQ-313
Maximum energy dissipation repetitive pulse	E_{AR}	–	–	100	mJ	[1] I_L = 17 A, $T_{J(0)} \leq 105°C$, 1 million cycles See Figure 6	PRQ-314
Voltage at OUT pin	$V_S - V_{OUT}$	-0.3	–	70	V	[1]	PRQ-46
Temperatures							
Junction temperature	T_J	-40	–	150	°C	[1]	PRQ-47
Dynamic temperature increase while switching	ΔT_J	–	–	60	K	[1]	PRQ-48
Storage temperature	T_{STG}	-55	–	150	°C	[1]	PRQ-49
ESD susceptibility							
ESD susceptibility (all pins)	$V_{ESD(HBM)}$	-2	–	2	kV	[1] Human Body Model "HBM" according to the AEC Q100-002	PRQ-50
ESD susceptibility OUT vs GND and VS connected	$V_{ESD(HBM)}$	-4	–	4	kV	[1] Human Body Model "HBM" according to the AEC Q100-002	PRQ-51
ESD susceptibility (all pins)	$V_{ESD(CDM)}$	-500	–	500	V	[1] Charge Device Model "CDM" according to AEC Q100-11	PRQ-52
ESD susceptibility (corner pins)	$V_{ESD(CDM)}$	-750	–	750	V	[1] Charge Device Model "CDM" according to AEC Q100-11	PRQ-53

1) Not subject to production test, specified by design.

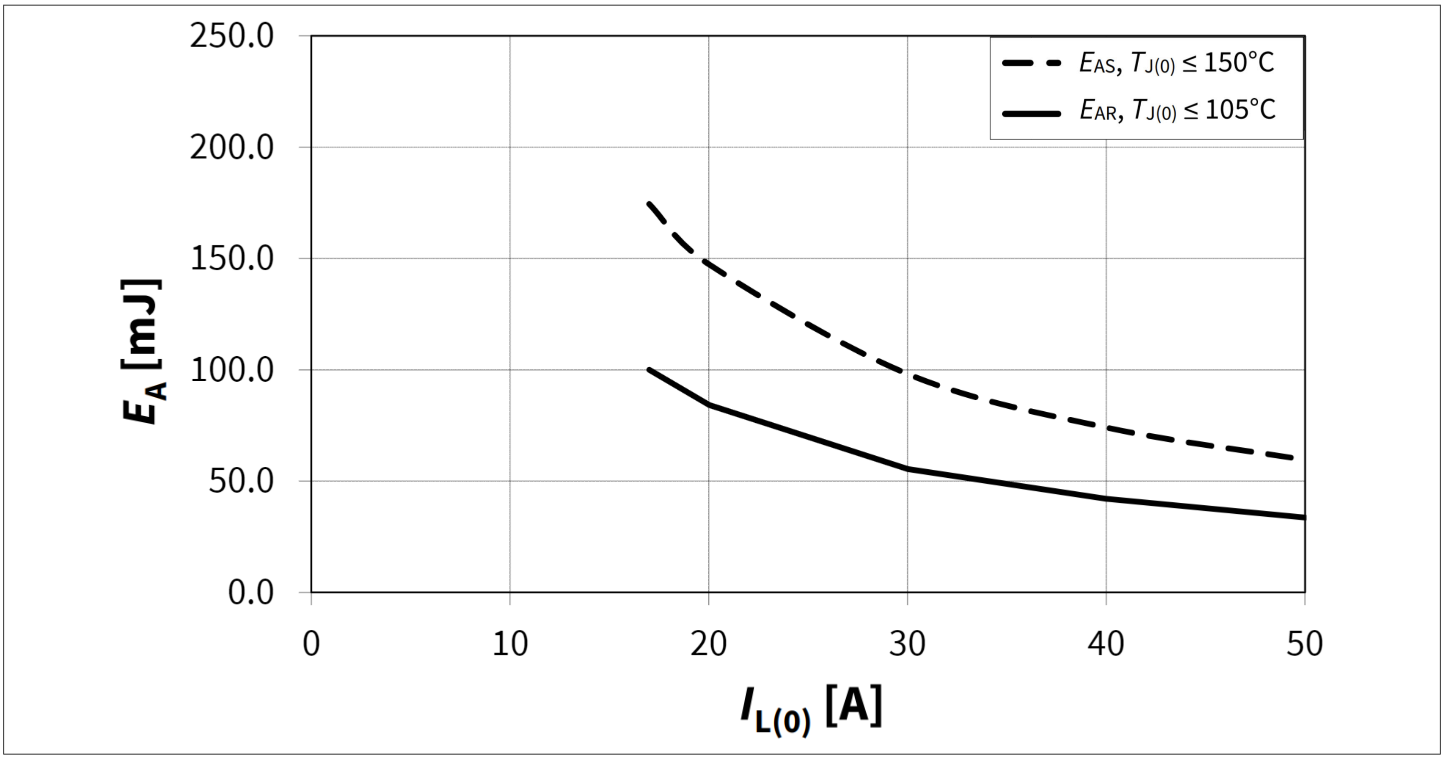


Figure 6 **Maximum energy dissipation for inductive switch off, $E_{AS/AR}$ vs. I_L**

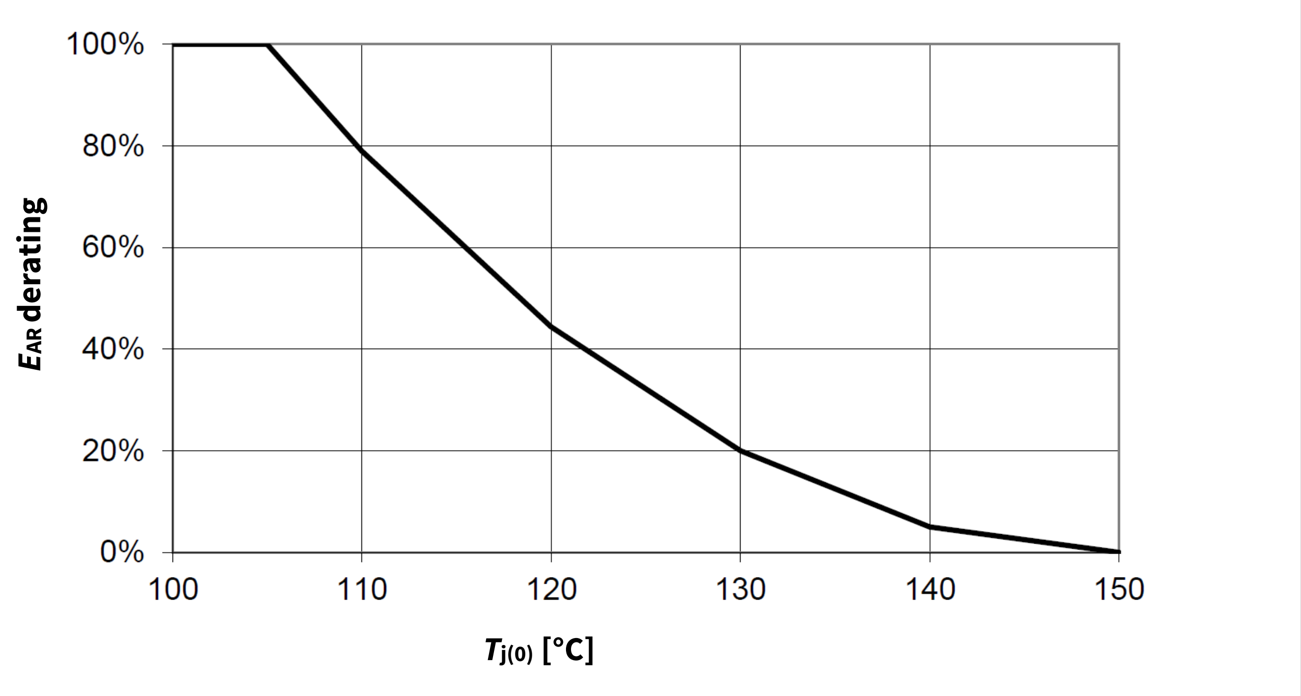


Figure 7 **Maximum energy dissipation repetitive pulse temperature derating**

***Note**:* *1. Stresses above the ones listed here may cause permanent damage to the device. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

2. 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.

4.2 Functional description

Table 4 Functional range

Parameter	Symbol	Values			Unit	Note or condition	P-Number
		Min.	Typ.	Max.			
Supply voltage range for nominal operation	$V_{S(NOM)}$	12	–	54	V	1)	PRQ-54
Supply voltage range for extended operation	$V_{S(EXT)}$	8	–	60	V	1) 2) Parameter deviation possible, long term overvoltage according to ISO 21780:2020(E), test-06	PRQ-55
Nominal load resistor	$R_{L(NOM)}$	–	2.8	–	Ω	1)	PRQ-299
Condition for accurate current measurement	$Min(V_S\text{-}V_{IS})$	–	–	8	V	1)	PRQ-312

1) Not subject to production test, specified by design.
2) Protection function still operative

Note: *Within the nominal operating range, the IC behaves as described in the circuit description.*
The electrical characteristics are inside the limits specified in the Electrical Characteristics table.

4.3 Thermal resistance

Note: *This thermal data was generated in accordance to JEDEC JESD51 standards. For more information, go to www.jedec.org.*

Table 5 Thermal resistance

Parameter	Symbol	Values			Unit	Note or condition	P-Number
		Min.	Typ.	Max.			
Junction to case	R_{thJC}	–	–	0.6	K/W	1)	PRQ-300
Junction to ambient	$R_{thJA(2s2p)}$	–	18	–	K/W	1) 2)	PRQ-301
Junction to ambient	$R_{thJA(1s0p)}$ /600mm^2	–	32	–	K/W	1) 3)	PRQ-302

1) Not subject to production test, specified by design.
2) Specified RthJA value is according to Jedec JESD51-2,-5,-7 at natural convection on FR4 2s2p board; the product (chip + package) was simulated on a 76.2 × 114.3 × 1.5 mm board with 2 inner copper layers (2 × 70 µm Cu, 2 × 35 µm Cu). Where applicable a thermal via array under the exposed pad contacted the first inner copper layer. Simulation done at TA = 105°C. The device is dissipating 2 W power.
3) Specified RthJA value is according to Jedec JESD51-2,-5,-7 at natural convection on FR4 1s0p board; the product (chip + package) was simulated on a 76.2 × 114.3 × 1.5 mm board with only one top copper layer 1 × 70 µm. Simulation done at TA = 105°C. The device is dissipating 2 W power.

Figure 8 is showing the typical thermal impedance of BTH50030-1LUA mounted according to JEDEC JESD51-2,-5,-7 at natural convection on FR4 1s0p and 2s2p boards.

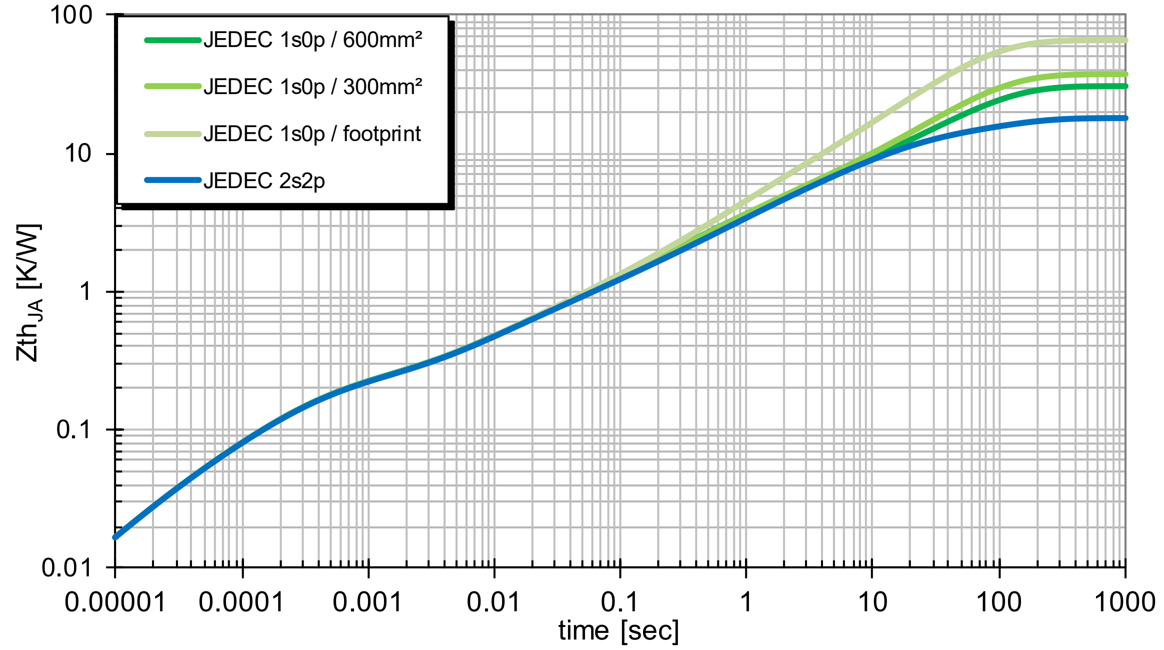


Figure 8 **Typical transient thermal impedance $Z_{th(JA)}$ = f(time) for different PCB conditions**

5 Functional description

5.1 Power stage

The power stage is built by a N-channel power MOSFET with a charge pump.

5.1.1 Output on-state resistance

The on-state resistance $R_{DS(ON)}$ depends on the supply voltage and on the junction temperature T_J. Chapter 6 shows the dependencies in terms of temperature and supply voltage, for the typical on-state resistance.

5.1.2 Switching resistive loads

Figure 9 shows the typical timing when switching a resistive load. The power stage has a defined switching behavior. Defined slew rates results in lowest EMC emission at minimum switching losses.

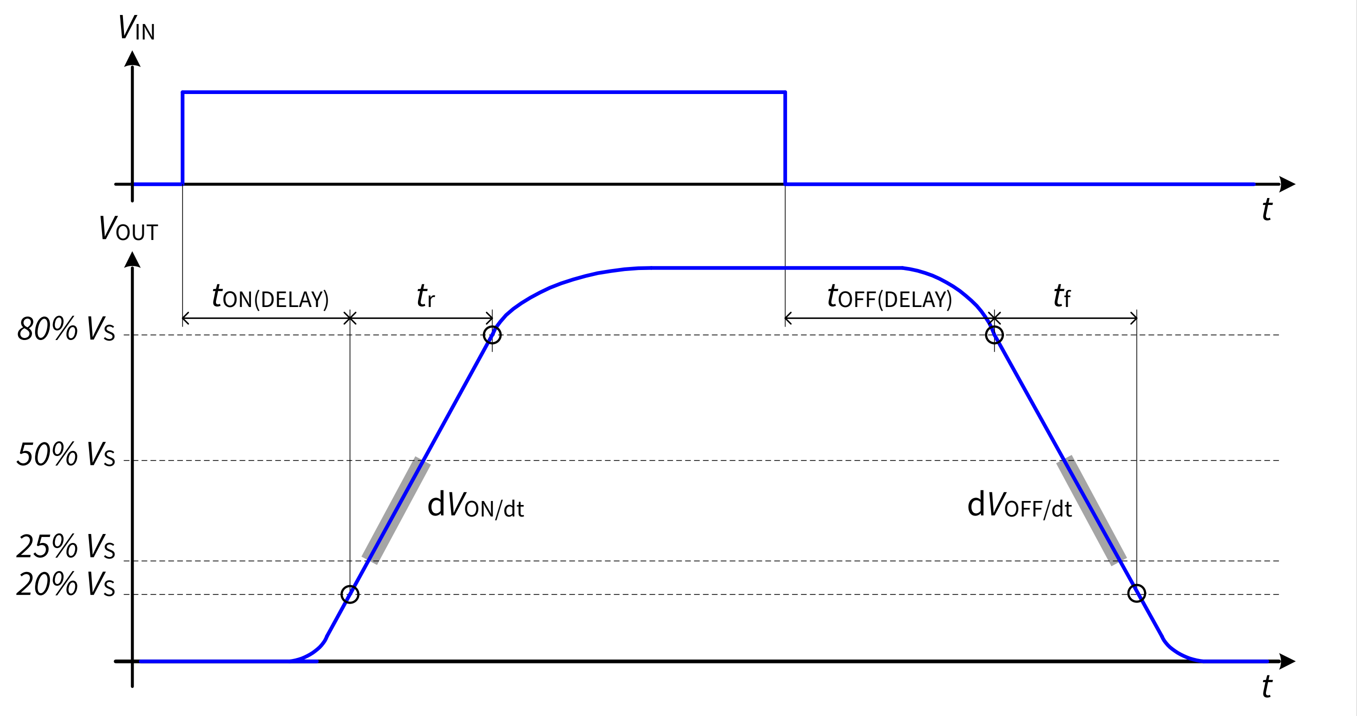


Figure 9 **Timings when switching a resistive load**

5.1.3 PWM switching

Consider the switching losses properly during this operation (see following equation):

$$P_{TOTAL} = \frac{switch\_on\_energy + switch\_off\_energy + \left(I_L^2 \times R_{DS(ON)} \times t_{DC}\right)}{Period} \tag{1}$$

If a fault condition occurs, ensure that the PWM frequency does not exceed a maximum retry frequency of f_{FAULT}.

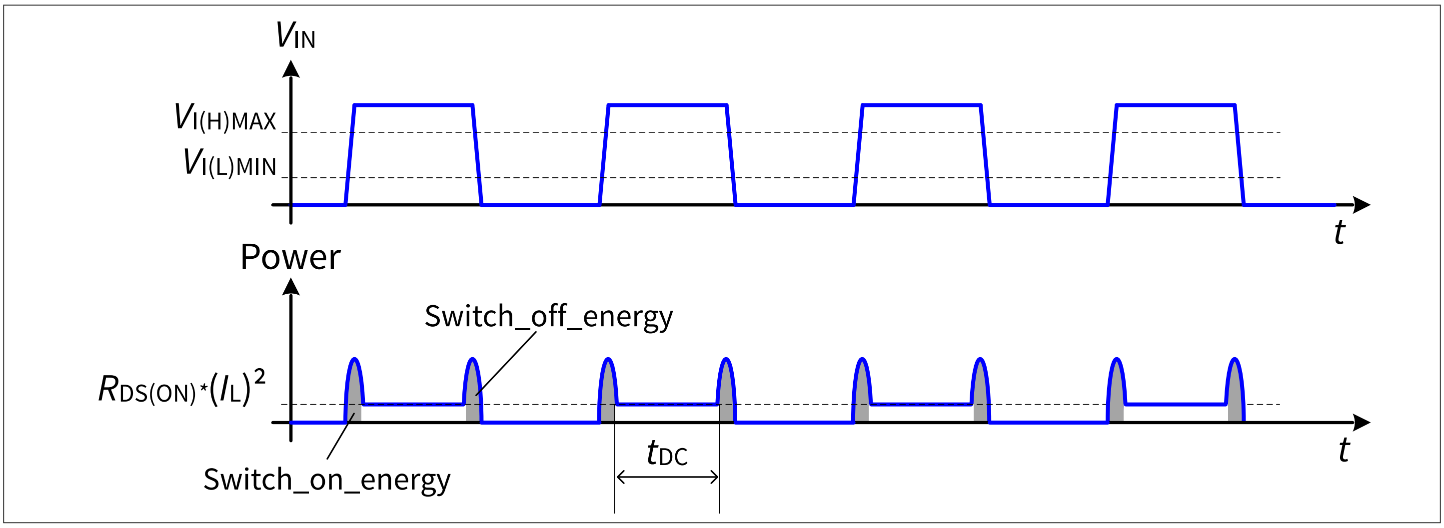


Figure 10 **Switching in PWM**

5.1.4 Switching inductive loads

5.1.4.1 Output clamping

When switching off inductive loads with high-side switches, the voltage V_{OUT} drops below ground potential, since the voltage polarity across the inductor has to be reversed to get a decrease of the inductive load current.

To prevent the destruction of the device due to high voltages, there is a smart clamping mechanism implemented that keeps negative output voltage to a certain level (V_S - $V_{DS(CL)}$). Please refer to Figure 11 and Figure 12 for details. Nevertheless, the maximum allowed load inductance remains limited.

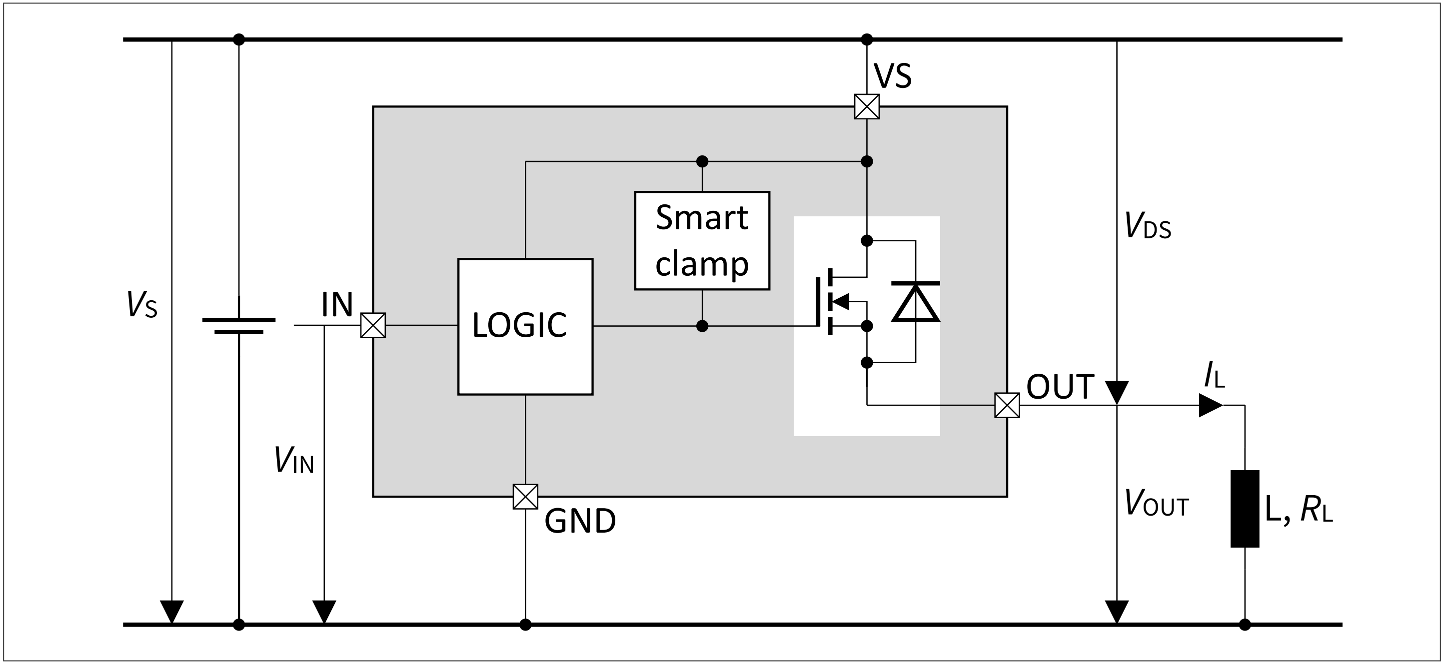


Figure 11 **Output clamp**

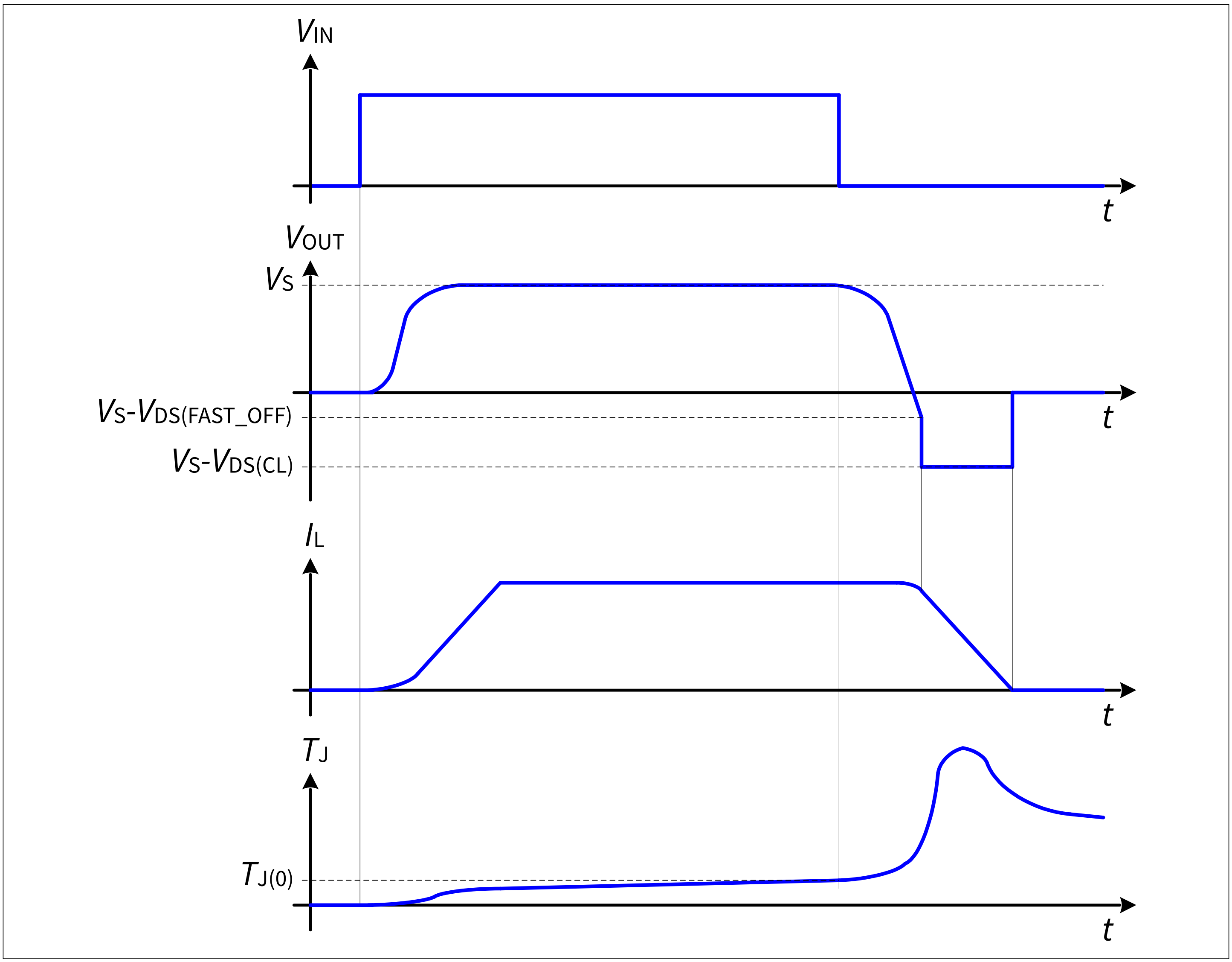


Figure 12 **Switching an inductance**

The device features a fast switch off when driving an inductive load in order to increase the energy capability. The fast turn off is triggered when V_{DS} is higher than $V_{DS(FAST\_OFF)}$. Please refer to Figure 12 for details.

The device must not be reactivated (V_{IN} goes from low to high) before $t_{IN(RESETDELAY)}$. Otherwise the device may not turn on and can be latched.

5.1.4.2 Maximum load inductance

During the demagnetization of inductive loads, the energy stored in the inductance must be dissipated in the device. This energy can be calculated with the following equation (2), where R_L is the parasitic resistance of the inductance:

$$E = V_{DS(CL)} \times \frac{L}{R_L} \times \left[\frac{(V_S - V_{DS(CL)})}{R_L} \times \ln\left(1 - \frac{R_L \times I_L}{(V_S - V_{DS(CL)})}\right) + I_L \right] \qquad (2)$$

(2) can be simplified under the assumption that $R_L = 0\ \Omega$. It then becomes:

$$E = \frac{1}{2} \times L \times I_L{}^2 \times \left(1 - \frac{V_S}{(V_S - V_{DS(CL)})}\right) \qquad (3)$$

The energy, which is converted into heat, is limited by the thermal design of the component. See Figure 6 for the maximum allowed energy dissipation as a function of the load current.

5.1.5 Advanced switch-off behavior

In order to reduce the device stress when switching off inductive and critical loads, the device provides a functionality which results in a faster switch off behavior.

The fast switch off functionality is triggered by each of the following conditions:

- The device is turned off by applying $V_{IN} < V_{I(L)MIN}$. During the switch off operation, V_{OUT} drops below V_S-$V_{DS(FAST\_OFF)}$. See Figure 12.
- The device is turned on or is already in on state ($V_{IN} > V_{I(H)MAX}$). The device then detects a short circuit condition ($I_L \geq I_{CL(0)}$) and initiates a protective switch off. Please refer to Chapter 5.3.1.1 and Chapter 5.3.1.2 for details.
- The device is turned on or is already in on state ($V_{IN} > V_{I(H)MAX}$). The device then detects an overpower condition. Please refer to Chapter 5.3.1.3 for details.

5.1.6 Inverse current behavior

When $V_{OUT} > V_S$, a current -I_L flows into the power output transistor (see Figure 13). This condition is known as inverse current.

If the channel is in off state, the current flows through the intrinsic body diode generating high power losses and therefore, an increase of the overall device temperature.

If the channel is in on state, $R_{DS(INV)}$ can be expected and power dissipation in the output stage is comparable to normal operation in $R_{DS(ON)}$.

During inverse current condition, the channel remains in on or off state as long as $|I_L| < |I_{L(NOM)}|$.

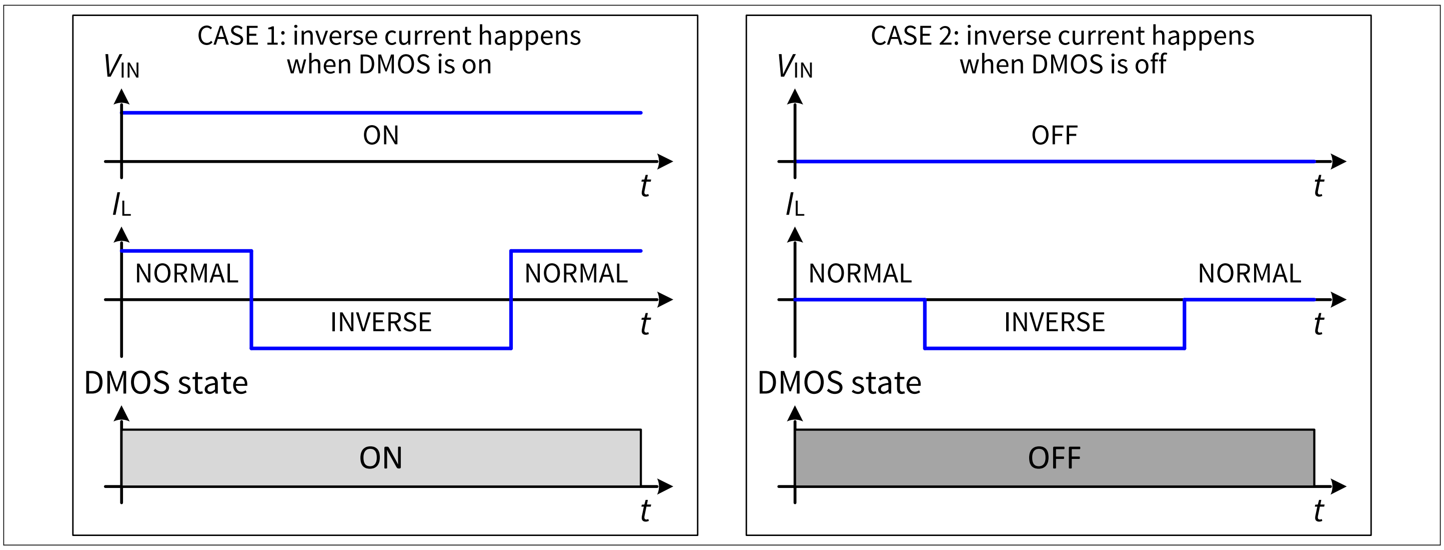


Figure 13 **Channel behavior in case of applied inverse current**

5.2 Digital input pins: IN and DEN

This section applies to the two digital pins of the device: IN and DEN.

The input circuitry is compatible with 3.3 V and 5 V logic levels. These two pins can also be directly tied to V_S.

The input circuitry tolerates negative voltages down to V_S-75 V: see the limits for parameters V_{IN} and V_{DEN} in Table 3.

The Figure 14 below shows the electrical equivalent input circuitry.

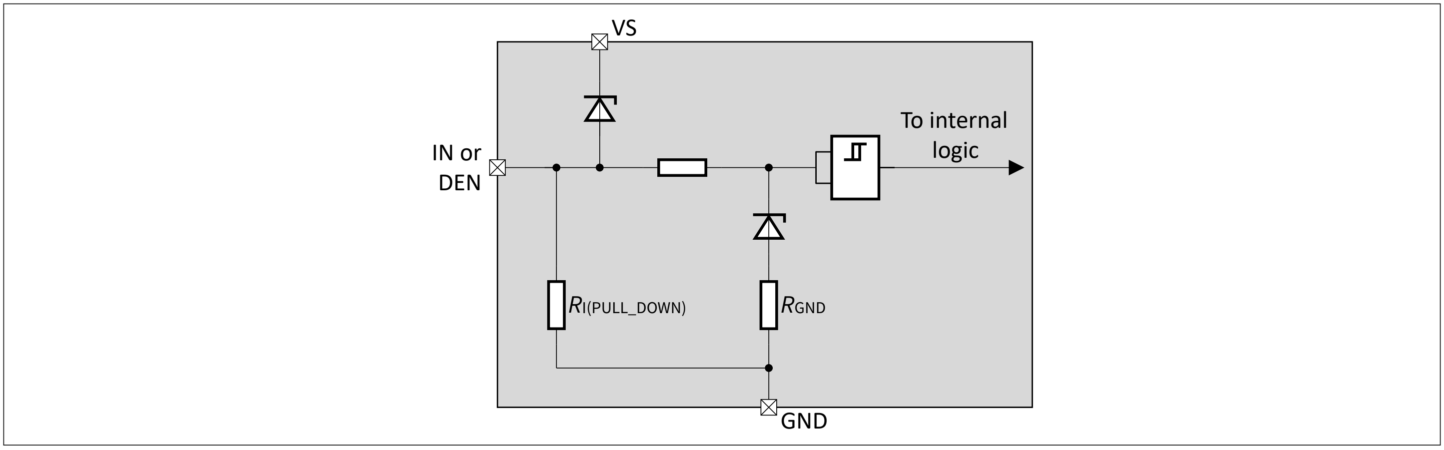


Figure 14 **Simplified schematics of the input pins circuitry**

5.3 Protection functions

The device provides integrated protective functions. They are designed to prevent the destruction of the IC when it is exposed to fault conditions described in the present datasheet. These fault conditions are considered as outside the normal operating range. Protection functions are designed neither for continuous nor for repetitive operation.

The Figure 15 below describes the typical functionality of the diagnosis and protection blocks.

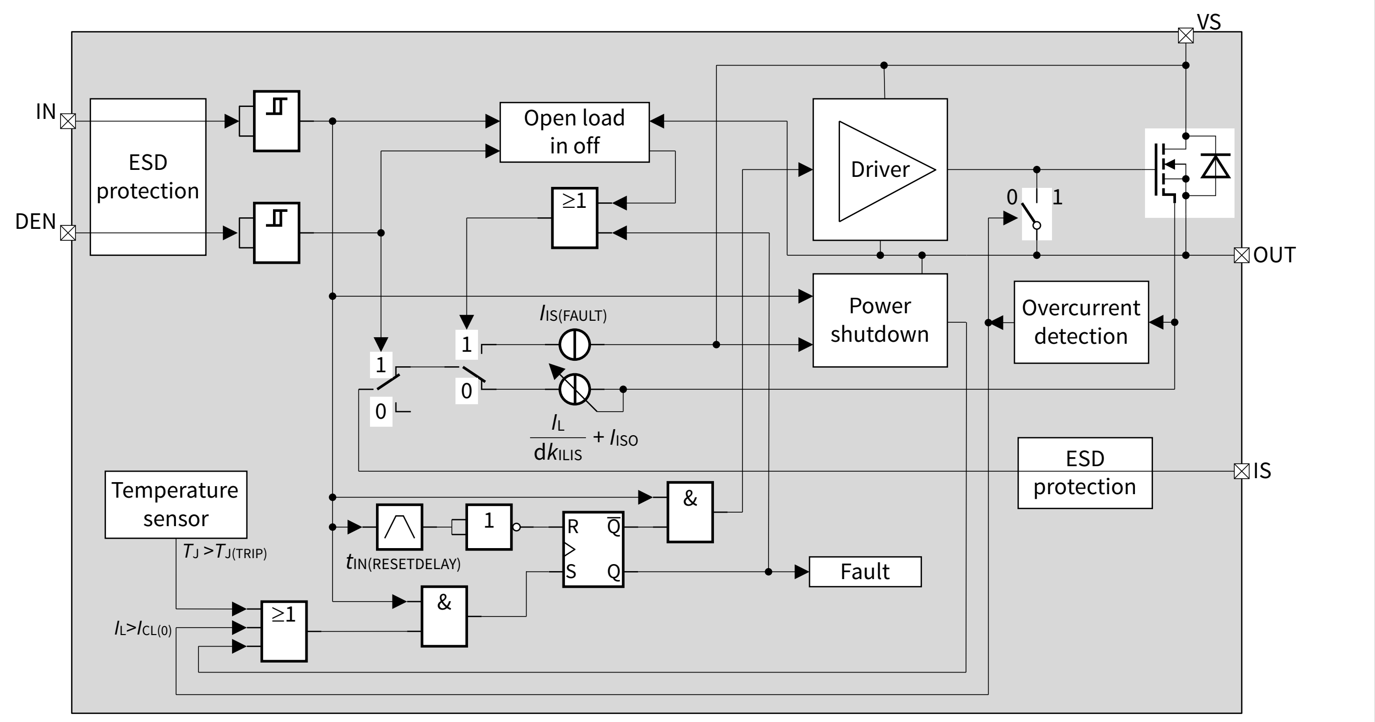


Figure 15 **Diagram of diagnosis and protection blocks**

5.3.1 Overload protection

In case of overload, high inrush current or short circuit to ground, the device offers several protection mechanisms.

An overcurrent, an overtemperature or an overpower shutdown switches off the output and latches the device.

There are 2 ways to reset the internal latch:

- Set $V_{IN} < V_{I(L)MIN}$ for $t > t_{IN(RESETDELAY)}$
- Set $V_S < V_{S(UVL)}$ for $t > t_{IN(RESETDELAY)}$

For overload (short circuit or overtemperature), the maximum retry cycle (f_{FAULT}) under fault condition must be considered.

5.3.1.1 Activation of the switch into short circuit (short circuit type 1)

When the switch is activated into short circuit, the current rises rapidly. When the output current reaches $I_{CL(0)}$ value, the device is latched and turns off after $t_{OFF(TRIP)}$ which leads to an overshoot on the output current above $I_{CL(0)}$.

5.3.1.2 Short circuit appearance when the device is already on (short circuit type 2)

When the device is in on state and a short circuit to ground appears at the output with an overcurrent higher than $I_{CL(0)}$, the device automatically turns off and latches.

5.3.1.3 Overpower shutdown (PSD)

The device integrates an overpower shutdown protection in order to limit the power dissipation. The target is to limit the maximum junction temperature in case of:

- A soft short circuit, where the short circuit resistance is too high to trigger the overcurrent protection ($I_L < I_{CL(0)}$)
- Repetitive short circuits
- A short circuit in applications with a high resistor and/or inductor in the battery line, where V_S drops below $V_{S(PSD)}$ and the load current does not reach the $I_{CL(0)}$

In such conditions, the overpower shutdown protection is activated and latches the device after $t_{PSD(UV)}$.

Note: *It also limits the maximum PWM frequency below the maximum value of* f_{IN}. *See* Figure 16 *below:*

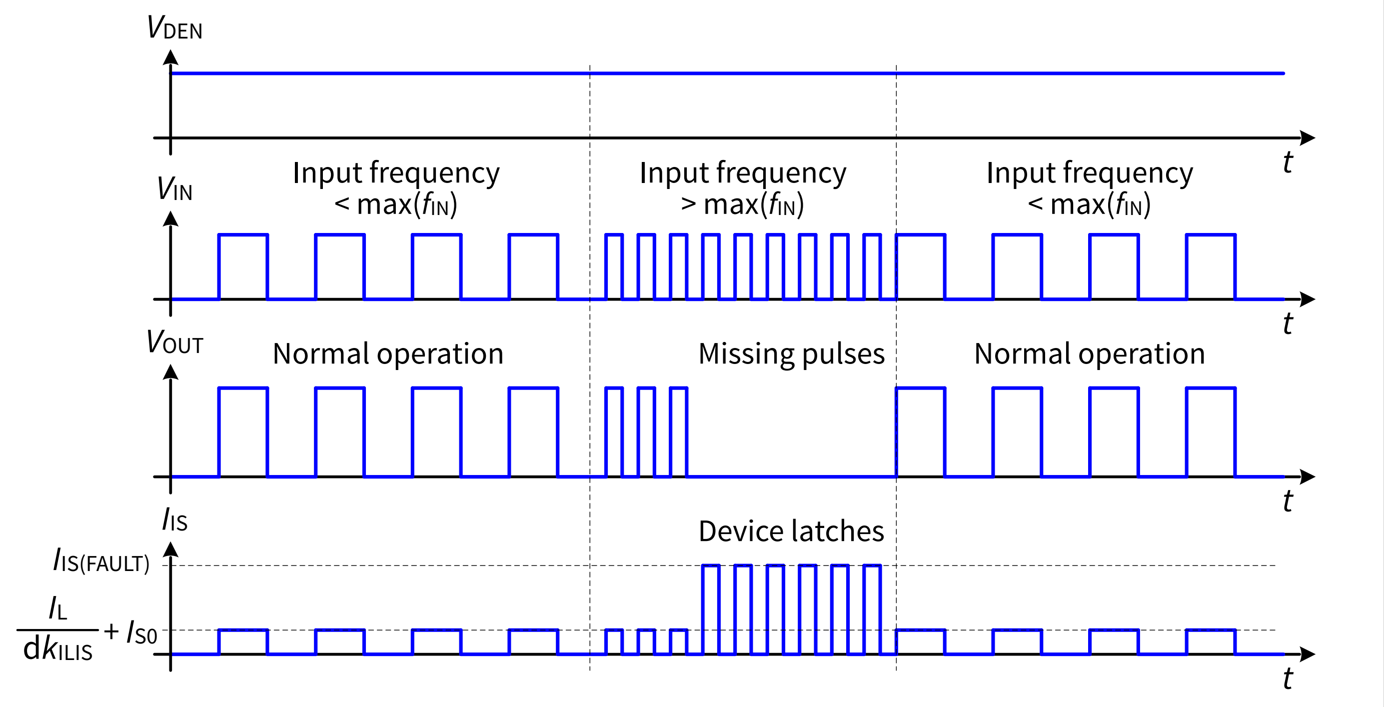


Figure 16 **Behavior during PWM operation above the maximum value of f_{IN}**

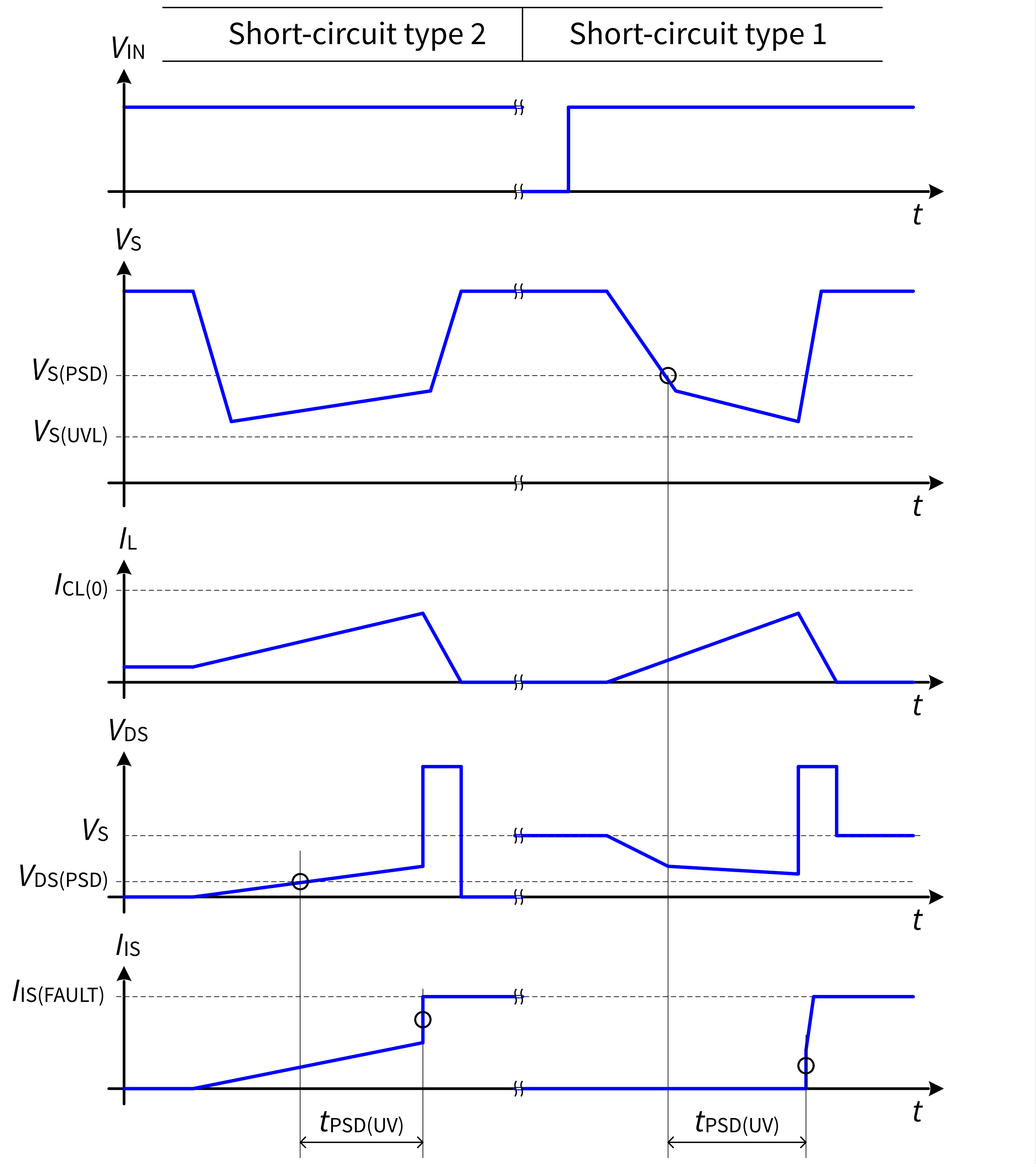


Figure 17 **Overpower shutdown behavior during supply voltage drops**

5.3.1.4 Temperature limitation in the power MOSFET

The device incorporates a temperature sensor. Triggering the overtemperature ($T_J > T_{J(TRIP)}$) switches off the power MOSFET to prevent destruction and latches the device.

5.3.2 Ground loss protection

In case of loss of device ground, while the load remains connected to ground, the device protects itself by automatically turning off (when it was previously on) or remains off, regardless of the voltage applied at IN pin.

5.4 Diagnosis functions

For diagnosis purposes, the device provides on the IS pin, either an image of the output load current, or a constant fault current.

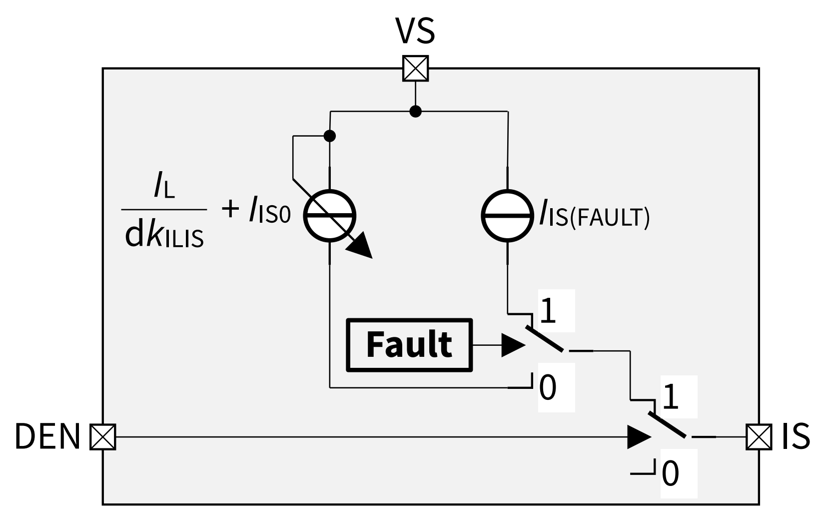


Figure 18 **Diagnosis block diagram**

5.4.1 Overview

Operation mode	V_{IN}	V_{DEN}	V_{OUT}	**Diagnosis output**
Normal condition	Low (OFF)	High	GND	$I_{IS(OFF)}$
Short circuit to GND			GND	$I_{IS(OFF)}$
Overtemperature			GND	$I_{IS(OFF)}$
Short circuit to VS			V_S	$I_{IS(FAULT)}$
Open load			$V_{OUT} > V_{OUT(OL\_OFF)}$ 1)	$I_{IS(FAULT)}$
			$V_{OUT} < V_{OUT(OL\_OFF)}$	$I_{IS(OFF)}$
Normal condition	High (ON)		$\sim V_S$	$I_{IS} = (I_L / dk_{ILIS}) + I_{IS0}$
Short circuit to GND			GND	$I_{IS(FAULT)}$
Overtemperature			GND	$I_{IS(FAULT)}$
Short circuit to VS			V_S	$I_{IS} \leq (I_L / dk_{ILIS}) + I_{IS0}$
Open load			V_S	I_{IS0} if positive, $I_{IS(OFF)}$ if negative
All conditions	N.a.	Low	N.a.	$I_{IS(OFF)}$

1) With additional pull-up resistor

5.4.2 Diagnosis in on state

A current proportional to the load current is provided at pin IS when the following conditions are fulfilled:

- The power output stage is switched on with $(V_S - V_{IS}) > Min(V_S - V_{IS})$
- The diagnosis is enabled ($V_{DEN} > V_{I(H)}$)
- No fault is present or was present
- The R_{IS} recommended value is 2kΩ

A current $I_{IS(FAULT)}$ is provided at IS pin when:

- The device is latched due to a previous overcurrent, overtemperature or overpower
- The diagnosis is enabled ($V_{DEN} > V_{I(H)}$)

Figure 19 and Figure 21 show the current sense as a function of the load current in the power MOSFET.
Usually, a pull-down resistor R_{IS} is connected to the current sense pin IS.
The dotted curve represents the typical sense current, assuming a typical dk_{ILIS} factor value.
The area between the two solid curves shows the current sense accuracy the device is able to provide.

$$I_{IS} = \frac{I_L}{dk_{ILIS}} + I_{IS0} \quad with \quad I_{IS} \geq 0 \tag{4}$$

Where the definition of dk_{ILIS} is:

$$dk_{ILIS} = \frac{I_{L2} - I_{L1}}{I_{IS2} - I_{IS1}} \tag{5}$$

the definition I_{IS0} is:

$$I_{IS0} = I_{IS1} - \frac{I_{L1}}{dk_{ILIS}} \tag{6}$$

and the definition of I_{L0} is:

$$I_{L0} = I_{L1} - (I_{IS1} \times dk_{ILIS}) \tag{7}$$

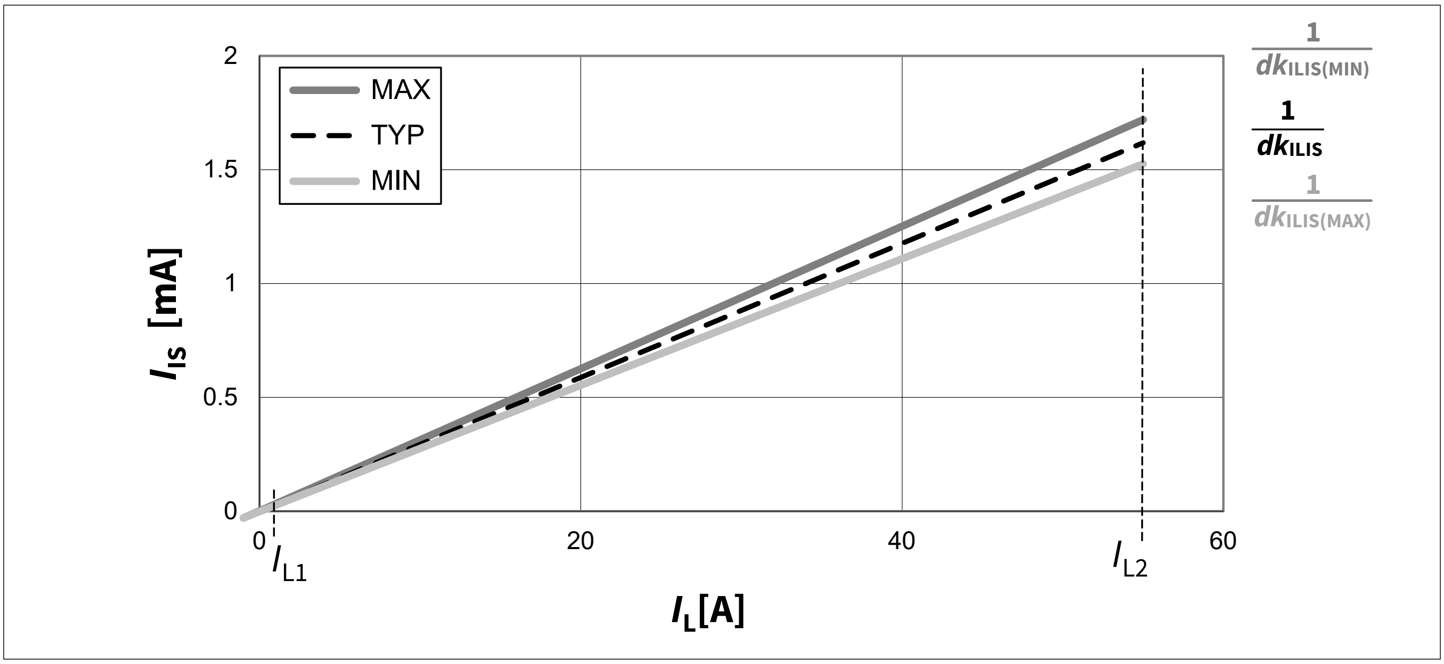


Figure 19 **Current sense at IS pin as a function of load current**

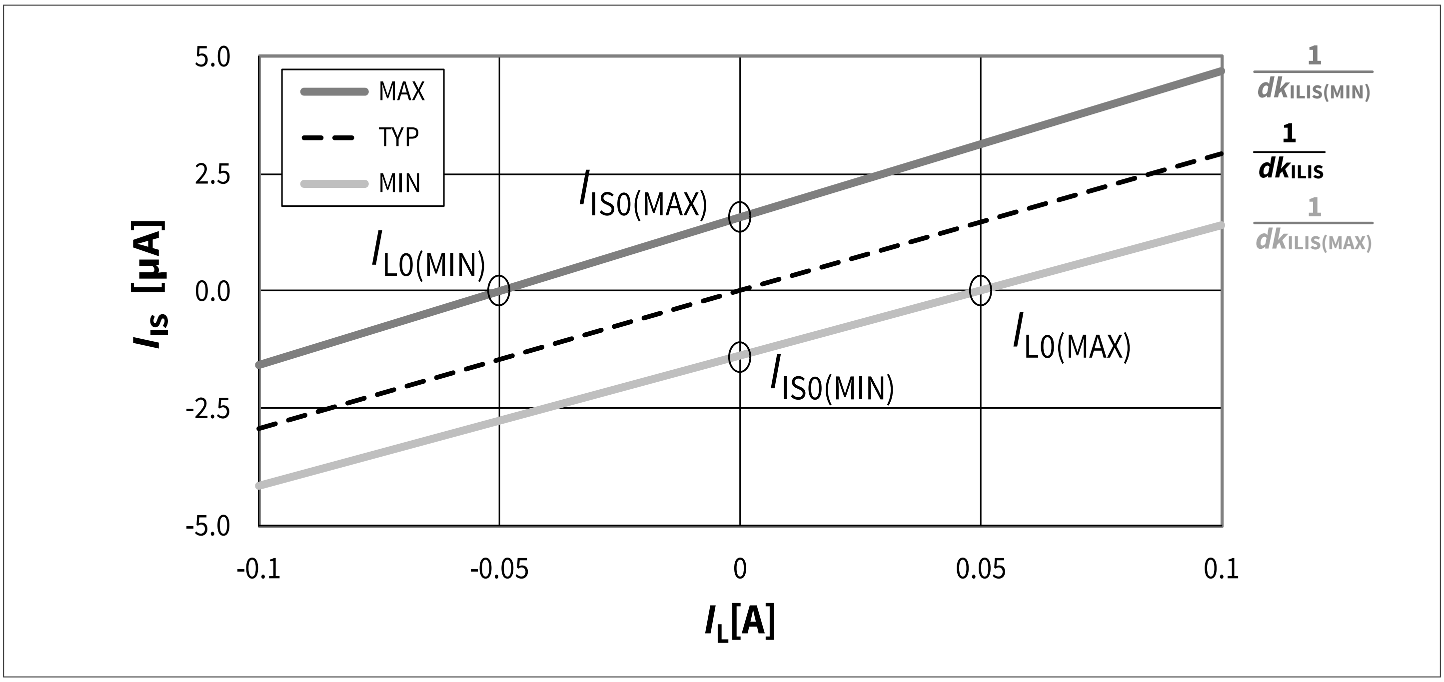


Figure 20 I_{IS0} and I_{L0} definition

5.4.2.1 Sense signal variation and calibration

In some applications, an enhanced accuracy is required around the device nominal current range $I_{L(NOM)}$. To improve the accuracy, a calibration in the application can be implemented; the best results are achieved using a two-point calibration.

Once calibrated, the I_{IS} variation over temperature and aging can be described with the parameters $\Delta(dk_{ILIS(CAL)})$ and the $\Delta I_{IS0(CAL)}$.

The grey solid line in Figure 21 is the current sense ratio calculated from the two-point calibration at a given temperature.

The slope of this line is calculated as:

$$\frac{1}{\mathrm{d}k_{\mathrm{ILIS(CAL)}}} = \frac{I_{\mathrm{IS(CAL)2}} - I_{\mathrm{IS(CAL)1}}}{I_{\mathrm{L(CAL)2}} - I_{\mathrm{L(CAL)1}}} \tag{8}$$

The offset is calculated as:

$$I_{\mathrm{IS0(CAL)}} = I_{\mathrm{IS(CAL)1}} - \frac{I_{\mathrm{L(CAL)1}}}{\mathrm{d}k_{\mathrm{ILIS(CAL)}}} = I_{\mathrm{IS(CAL)2}} - \frac{I_{\mathrm{L(CAL)2}}}{\mathrm{d}k_{\mathrm{ILIS(CAL)}}} \tag{9}$$

These two parameters, slope and offset, are accurate when the device is operated at the same ambient temperature as the one used during the calibration.

However, both parameters are temperature and lifetime dependant by a few percent, which results in an additional inaccuracy when the ambient temperature changes or when the device has been operated for a long time.

The grey area in Figure 21 shows the range of values for these two parameters across temperature and load current.

It is visible that the accuracy of the load current sensing is improved, when compared to the darkest lines showing the spread without calibration.

In the application, when a sense current value I_{IS} is measured, the corresponding load current can be calculated as follows:

$$I_{\mathrm{L}} = \mathrm{d}k_{\mathrm{ILIS(CAL)}} \times \left(1 + \Delta\left(\mathrm{d}k_{\mathrm{ILIS(CAL)}}\right)\right) \times \left(I_{\mathrm{IS}} - I_{\mathrm{IS0(CAL)}} - \Delta I_{\mathrm{IS0(CAL)}}\right) \tag{10}$$

where:

- $\mathrm{d}k_{\mathrm{ILIS(CAL)}}$ is the current sense ratio calculated after two-points calibration, as defined in (8)
- $\Delta(\mathrm{d}k_{\mathrm{ILIS(CAL)}})$ is the additional variation of the current sense ratio over life time and temperature (in absolute value, not in percentage)
- $I_{\mathrm{IS0(CAL)}}$ is the current sense offset calculated after two points calibration, as defined in (9), and
- $\Delta I_{\mathrm{IS0(CAL)}}$ is the additional variation of the offset over life time and temperature (in absolute value, not in percentage)

For a calibration at 25°C, $\Delta I_{\mathrm{IS0(CAL)}}$ varies over temperature and life time according to the following equations. For positive $I_{\mathrm{IS0(CAL)}}$ values ($I_{\mathrm{IS0(CAL)}} > 0$):

$$MaxI_{\mathrm{IS0}}(@T_{\mathrm{J}} = 150°C) - MaxI_{\mathrm{IS0}}(@T_{\mathrm{J}} = 25°C) \leq \Delta I_{\mathrm{IS0(CAL)}} \leq MaxI_{\mathrm{IS0}}(@T_{\mathrm{J}} = -40°C) - MaxI_{\mathrm{IS0}}(@T_{\mathrm{J}} = 25°C) \tag{11}$$

For negative $I_{\mathrm{IS0(CAL)}}$ values ($I_{\mathrm{IS0(CAL)}} < 0$):

$$MinI_{\mathrm{IS0}}(@T_{\mathrm{J}} = 150°C) - MinI_{\mathrm{IS0}}(@T_{\mathrm{J}} = 25°C) \geq \Delta I_{\mathrm{IS0(CAL)}} \geq MinI_{\mathrm{IS0}}(@T_{\mathrm{J}} = -40°C) - MinI_{IS0}(@T_{\mathrm{J}} = 25°C) \tag{12}$$

(10) actually provides four solutions for load current, considering that $\Delta(\mathrm{d}k_{\mathrm{ILIS(CAL)}})$ and $\Delta I_{\mathrm{IS0(CAL)}}$ can both be positive or negative. The load current I_{L} corresponding to a known sense current I_{IS} spreads between:

- A minimum I_{L} value resulting from the combination of lowest $\Delta(\mathrm{d}k_{\mathrm{ILIS(CAL)}})$ value and highest $\Delta I_{\mathrm{IS0(CAL)}}$ and
- A maximum I_{L} value resulting from the combination of highest $\Delta(\mathrm{d}k_{\mathrm{ILIS(CAL)}})$ value and lowest $\Delta I_{\mathrm{IS0(CAL)}}$

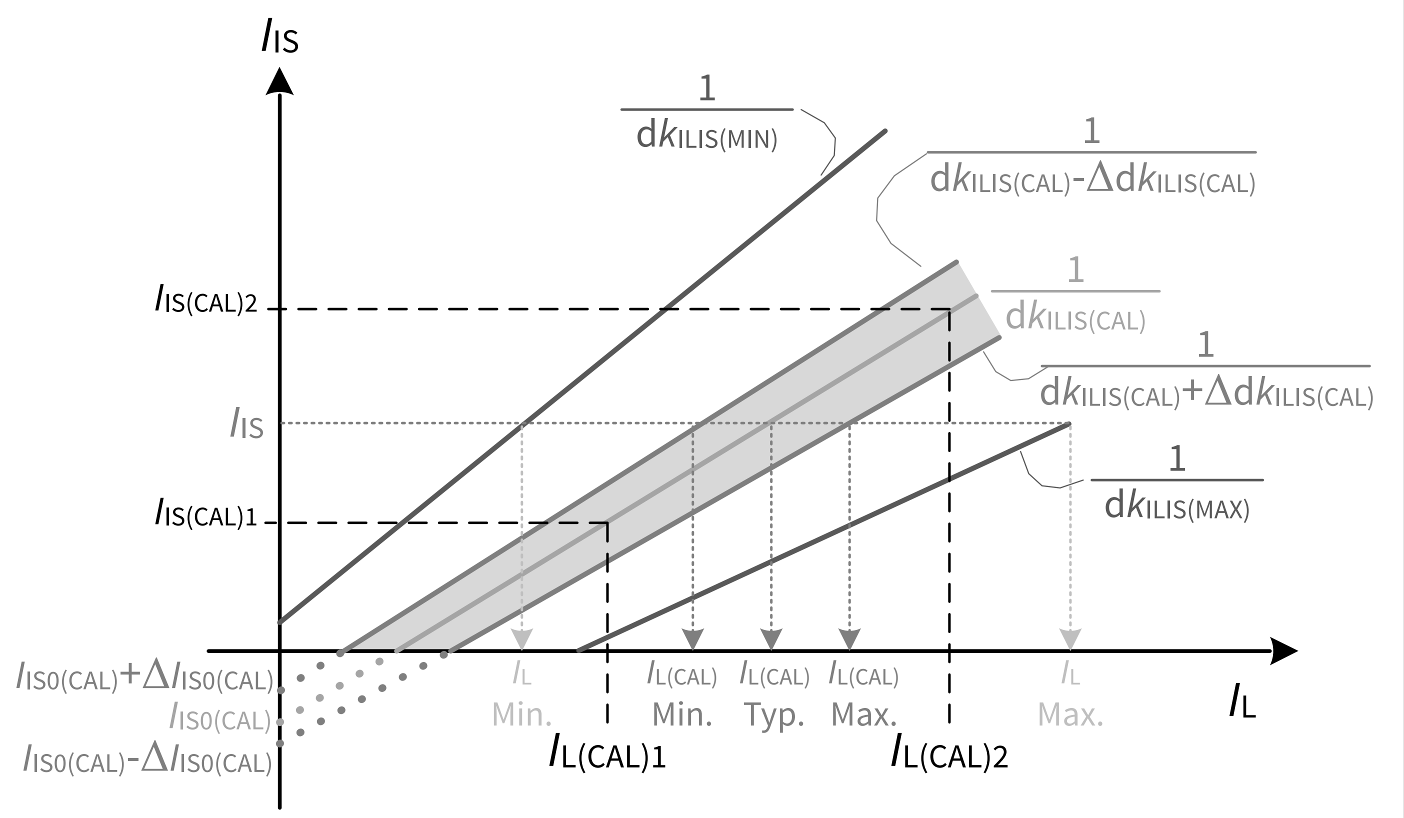


Figure 21 Improved current sense accuracy after 2 points calibration

5.4.2.2 Sense signal timing

The Figure 22 below shows the timings at turn on and when enabling/disabling the current sense feature through the DEN pin:

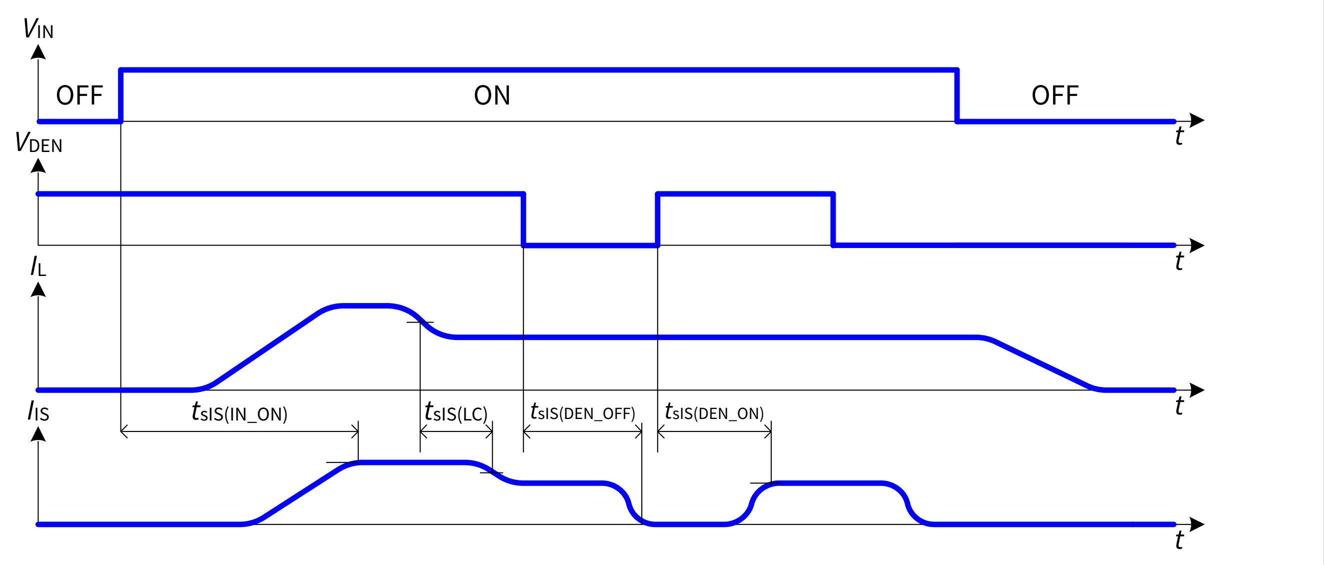


Figure 22 Current sense timing in normal operation

The Figure 23 below describes the IS pin behavior under protection conditions:

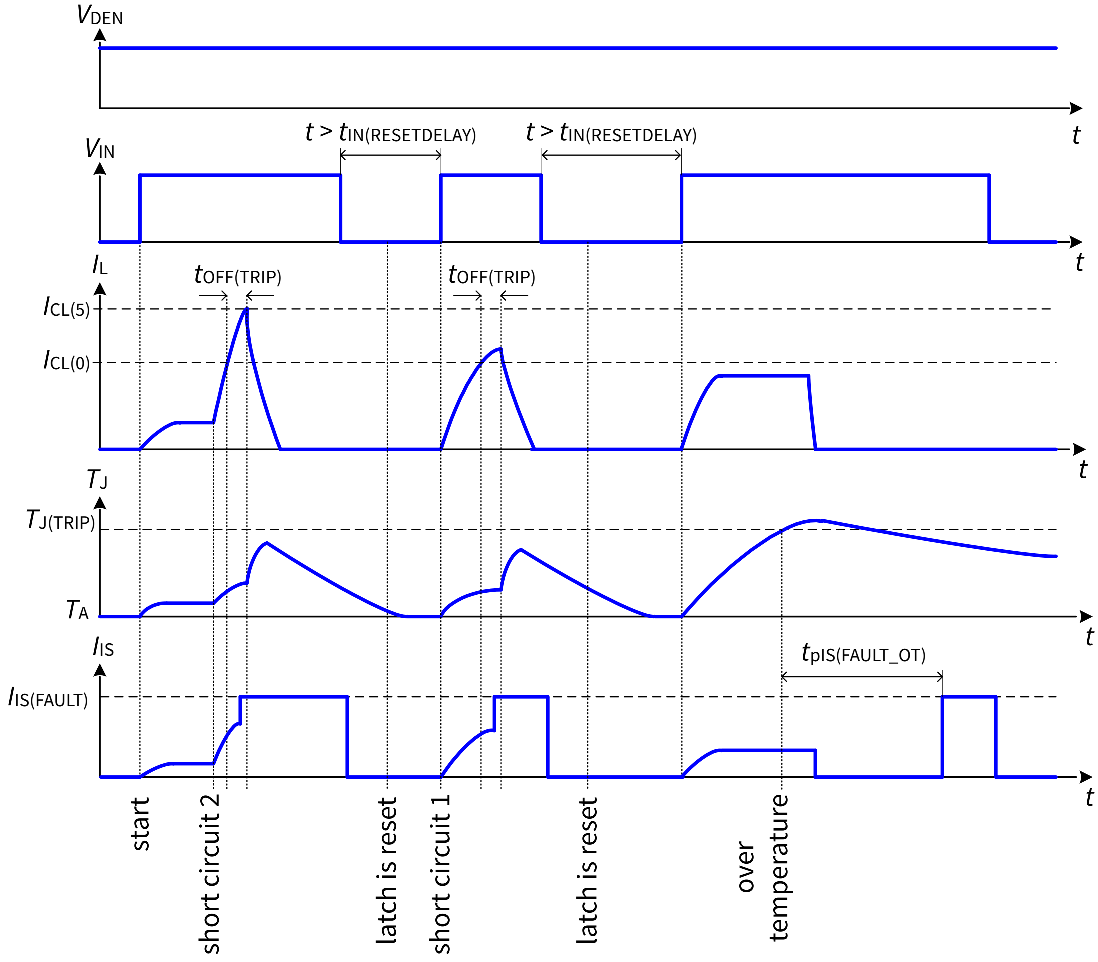


Figure 23 IS pin behavior under protection

5.4.3 Diagnosis in off state

The device features a detection of open load when it is in off state. An internal comparator is monitoring V_{OUT}. If $V_{OUT} > V_{OUT(OL\_OFF)}$ and $V_{DEN} > V_{I(H)MAX}$, the current at IS pin is $I_{IS(FAULT)}$.
In order to pull-up OUT in case of open load condition, an external pull-up resistor must be connected between VS and OUT pins. This external resistor must be switchable to keep the quiescent current as low as possible on VS pin.

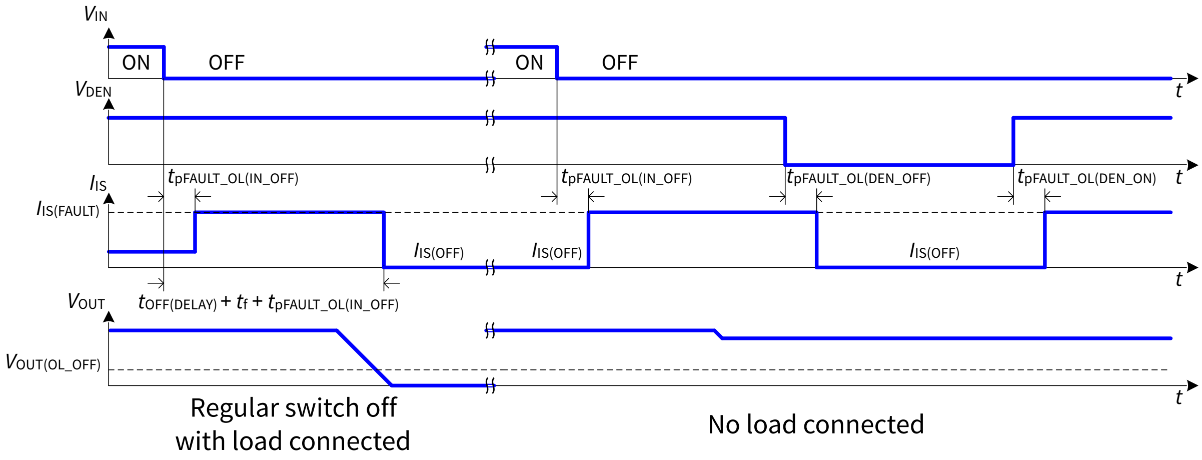


Figure 24 Behavior of the open load detection in off feature with and without load connected

5.5 Electrical characteristics

Table 6 Electrical characteristics table

V_S = 12 V to 54 V, T_J = -40°C to +150°C unless otherwise specified. For a given temperature or voltage range, typical values are specified at V_S = 48 V, T_J = 25°C.

Parameter	Symbol	Values			Unit	Note or condition	P-Number
		Min.	Typ.	Max.			
Operating and standby currents							
Standby current on VS pin with load	$I_{VS(OFF\_L)}$	–	5	7	µA	$V_{IN} = V_{DEN} = V_{OUT} = 0$ V, $R_{IS} = 2$ kΩ, $T_J \leq 85$°C, 7 ms after $V_{IN} \leq V_{I(L)MIN}$	PRQ-65
Standby current on VS pin with load	$I_{VS(OFF\_L)}$	–	10	100	µA	$V_{IN} = V_{DEN} = V_{OUT} = 0$ V, $R_{IS} = 2$ kΩ, $T_J \leq 150$°C, 7 ms after $V_{IN} \leq V_{I(L)MIN}$	PRQ-67
Standby current on VS pin with load and DEN active	$I_{VS(OFF\_DEN)}$	–	200	400	µA	$V_{IN} = V_{OUT} = 0$ V, $V_{DEN} = 5$ V, $R_{IS} = 2$ kΩ, $T_J \leq 85$°C, 7 ms after $V_{IN} \leq V_{I(L)MIN}$	PRQ-66
Supply current on GND pin in on state with digital level on IN pin	$I_{GND(ON\_dig\text{-}lev)}$	–	2.5	4.2	mA	$V_{I(H)MAX} \leq V_{IN} \leq 5.5$ V $V_{I(H)MAX} \leq V_{DEN} \leq 5.5$ V	PRQ-68
Supply current on GND pin in on state with high voltage on IN pin	$I_{GND(ON\_High\text{-}V)}$	–	3	5.5	mA	$5.5\text{ V} < V_{IN} \leq V_S$ $5.5\text{ V} < V_{DEN} \leq V_S$	PRQ-324
Ground resistor	R_{GND}	130	180	230	Ω	–	PRQ-69
Power stage							
On-state resistance in forward condition	$R_{DS(ON)}$	–	3.0	–	mΩ	[1] T_J = 25°C	PRQ-303
On-state resistance in forward condition	$R_{DS(ON)}$	–	5.8	7.0	mΩ	T_J = 150°C	PRQ-304
On-state resistance in inverse condition	$R_{DS(INV)}$	–	3.0	7.0	mΩ	–	PRQ-352
Nominal load current	$I_{L(NOM)}$	22.5	25	–	A	[1] T_A = 85°C, $T_J \leq 150$°C $R_{thJA(2s2p)}$	PRQ-310
Drain to source smart clamp voltage	$V_{DS(CL)}$	70	76	–	V	$V_{DS(CL)} = V_S - V_{OUT}$ I_L = 10 mA	PRQ-89
Drain to source smart clamp voltage after a short-circuit detection	$V_{DS(CL\_SC)}$	–	70	–	V	$V_{DS(CL\_SC)} = V_S - V_{OUT}$ after activation of the short-circuit protection ($I_L > I_{CL(0)}$)	PRQ-329
Body diode forward voltage	V_F	–	0.6	0.8	V	I_L = -25A, T_J = 150°C	PRQ-91

(table continues...)

Table 6 **(continued) Electrical characteristics table**

V_S = 12 V to 54 V, T_J = -40°C to +150°C unless otherwise specified. For a given temperature or voltage range, typical values are specified at V_S = 48 V, T_J = 25°C.

Parameter	Symbol	Values			Unit	Note or condition	P-Number
		Min.	Typ.	Max.			
Output leakage current	$I_{OUT(OFF)}$	–	10	20	µA	$V_{IN} = V_{DEN} = V_{OUT} = 0$ V, $V_S = 60$ V, $T_J \leq 85$°C, 7 ms after $V_{IN} < V_{I(L)MIN}$	PRQ-92
Output leakage current	$I_{OUT(OFF)}$	–	10	50	µA	$V_{IN} = V_{DEN} = V_{OUT} = 0$ V, $V_S = 60$ V, $T_J \leq 150$°C, 7 ms after $V_{IN} < V_{I(L)MIN}$	PRQ-93
Turn on slew rate	$dV_{ON/dt}$	0.75	1.5	3	V/µs	V_{OUT} from 25% to 50% of V_S $R_L = R_{L(NOM)}$, $V_S = 48$ V	PRQ-94
Turn on slew rate	$dV_{ON/dt}$	0.22	0.5	1	V/µs	[1] V_{OUT} from 25% to 50% of V_S $R_L = R_{L(NOM)} / 2$, $V_S = 24$ V	PRQ-389
Turn off slew rate	$-dV_{OFF/dt}$	0.75	1.5	3	V/µs	V_{OUT} from 50% to 25% of V_S $R_L = R_{L(NOM)}$, $V_S = 48$ V	PRQ-97
Turn off slew rate	$-dV_{OFF/dt}$	0.22	0.5	1	V/µs	[1] V_{OUT} from 50% to 25% of V_S $R_L = R_{L(NOM)} / 2$, $V_S = 24$ V	PRQ-390
Rising time during turn on	t_r	15	35	70	µs	V_{OUT} from 20% to 80% of V_S $R_L = R_{L(NOM)}$, $V_S = 48$ V	PRQ-100
Rising time during turn on	t_r	17	45	90	µs	[1] V_{OUT} from 20% to 80% of V_S $R_L = R_{L(NOM)} / 2$, $V_S = 24$ V	PRQ-391
Falling time during turn off	t_f	15	35	70	µs	V_{OUT} from 80% to 20% of V_S $R_L = R_{L(NOM)}$, $V_S = 48$ V	PRQ-103
Falling time during turn off	t_f	17	45	90	µs	[1] V_{OUT} from 80% to 20% of V_S $R_L = R_{L(NOM)} / 2$, $V_S = 24$ V	PRQ-392
Turn on time	$t_{ON(DELAY)}$	22	55	125	µs	From ($V_{IN} > V_{I(H)}$) to V_{OUT} = (20% x V_S) $R_L = R_{L(NOM)}$, $V_S = 48$ V	PRQ-106
Turn on time	$t_{ON(DELAY)}$	22	65	150	µs	[1] From ($V_{IN} > V_{I(H)}$) to V_{OUT} = (20% x V_S) $R_L = R_{L(NOM)} / 2$, $V_S = 24$ V	PRQ-393
Turn off time	$t_{OFF(DELAY)}$	50	130	225	µs	From ($V_{IN} < V_{I(L)}$) to V_{OUT} = (80% x V_S) $R_L = R_{L(NOM)}$, $V_S = 48$ V	PRQ-109

(table continues...)

Table 6 (continued) Electrical characteristics table

V_S = 12 V to 54 V, T_J = -40°C to +150°C unless otherwise specified. For a given temperature or voltage range, typical values are specified at V_S = 48 V, T_J = 25°C.

Parameter	Symbol	Values			Unit	Note or condition	P-Number
		Min.	Typ.	Max.			
Turn off time	$t_{OFF(DELAY)}$	40	110	200	µs	[1] From ($V_{IN} < V_{I(L)}$) to V_{OUT} = (80% x V_S) $R_L = R_{L(NOM)}$ / 2, V_S = 24 V	PRQ-394
Switch on energy	E_{ON}	–	12.5	–	mJ	[1] $R_L = R_{L(NOM)}$, V_S = 48 V	PRQ-305
Switch on energy	E_{ON}	–	9	–	mJ	[1] $R_L = R_{L(NOM)}$ / 2, V_S = 24 V	PRQ-396
Switch off energy	E_{OFF}	–	10	–	mJ	[1] $R_L = R_{L(NOM)}$, V_S = 48 V	PRQ-306
Switch off energy	E_{OFF}	–	7	–	mJ	[1] $R_L = R_{L(NOM)}$ / 2, V_S = 24 V	PRQ-398
VS pin							
Power supply undervoltage shutdown	$V_{S(UVL)}$	3.0	3.7	4.4	V	V_S decreasing	PRQ-118
Power supply undervoltage turn on	$V_{S(UVH)}$	4.2	5.0	6.0	V	V_S increasing	PRQ-119
Digital input pins: IN and DEN							
High level input threshold	$V_{I(H)}$	–	–	2.5	V	–	PRQ-120
Low level input threshold	$V_{I(L)}$	0.5	–	–	V	–	PRQ-121
Input voltage hysteresis	$V_{I(HYS)}$	–	0.2	–	V	–	PRQ-122
Input pull-down resistor	$R_{I(PULL\_DOWN)}$	100	200	–	kΩ	–	PRQ-123
Protection: overload							
Current trip detection level	$I_{CL(0)}$	55	85	110	A	T_J = -40°C	PRQ-403
Current trip detection level	$I_{CL(0)}$	55	80	100	A	[1] T_J = 25°C	PRQ-307
Current trip detection level	$I_{CL(0)}$	55	75	90	A	T_J = 150°C	PRQ-404
Current trip maximum level at 5 A/µs	$I_{CL(5)}$	55	100	125	A	dI_L/dt = 5 A/µs T_J = -40°C	PRQ-407
Current trip maximum level at 5 A/µs	$I_{CL(5)}$	55	95	115	A	[1] dI_L/dt = 5 A/µs T_J = 25°C	PRQ-308
Current trip maximum level at 5 A/µs	$I_{CL(5)}$	55	90	105	A	dI_L/dt = 5 A/µs T_J = 150°C	PRQ-408
Overload shutdown delay time	$t_{OFF(TRIP)}$	–	3.5	6	µs	–	PRQ-309

(table continues...)

Table 6 (continued) Electrical characteristics table

V_S = 12 V to 54 V, T_J = -40°C to +150°C unless otherwise specified. For a given temperature or voltage range, typical values are specified at V_S = 48 V, T_J = 25°C.

Parameter	Symbol	Values			Unit	Note or condition	P-Number
		Min.	Typ.	Max.			
Thermal shutdown temperature	$T_{J(TRIP)}$	150	175	200	°C	[1] V_S in $V_{S(EXT)}$ range	PRQ-141
Over power shutdown detection level	$V_{DS(PSD)}$	1.25	1.5	1.75	V	[1]	PRQ-142
Over power shutdown activation level	$V_{S(PSD)}$	3.25	4.25	5.25	V	[1]	PRQ-143
Over power shutdown time	$t_{PSD(UV)}$	10	100	350	µs	Start: when [$V_S < V_{S(PSD)}$ and $V_{DS} > V_{DS(PSD)}$] Stop: when I_{IS} > 80% $I_{IS(FAULT)}$	PRQ-144
Diagnosis function: current sense characteristics							
Current sense differential ratio	dk_{ILIS}	31500	34000	36500	–	I_{L0} max $\le I_L \le I_{CL(0)}$ min $V_S - V_{IS} \ge Min(V_S - V_{IS})$	PRQ-145
Calculated offset on IL when IS= 0 A at Tj = -40°C	I_{L0}	-50	0	50	mA	$V_S - V_{IS} \ge Min(V_S - V_{IS})$ T_J = -40°C	PRQ-316
Calculated offset on IL when IS= 0 A at Tj = 25°C	I_{L0}	-40	0	40	mA	[1] $V_S - V_{IS} \ge Min(V_S - V_{IS})$ T_J = 25°C	PRQ-317
Calculated offset on IL when IS= 0 A at Tj = 150°C	I_{L0}	-30	0	30	mA	$V_S - V_{IS} \ge Min(V_S - V_{IS})$ T_J = 150°C	PRQ-318
Calculated offset on IS when IL = 0 A at Tj = -40°C	I_{IS0}	-1.37	0	1.59	µA	[1] $V_S - V_{IS} \ge Min(V_S - V_{IS})$ T_J = -40°C	PRQ-319
Calculated offset on IS when IL = 0 A at Tj = 25°C	I_{IS0}	-1.10	0	1.27	µA	[1] $V_S - V_{IS} \ge Min(V_S - V_{IS})$ T_J = 25°C	PRQ-320
Calculated offset on IS when IL = 0 A at Tj = 150°C	I_{IS0}	-0.83	0	0.96	µA	[1] $V_S - V_{IS} \ge Min(V_S - V_{IS})$ T_J = 150°C	PRQ-321
Current sense ratio spread over temperature and repetitive pulse operation	$\Delta(dk_{ILIS(CAL)})$	-5	0	+5	%	[1]	PRQ-168

(table continues...)

Table 6 (continued) Electrical characteristics table

V_S = 12 V to 54 V, T_J = -40°C to +150°C unless otherwise specified. For a given temperature or voltage range, typical values are specified at V_S = 48 V, T_J = 25°C.

Parameter	Symbol	Values			Unit	Note or condition	P-Number
		Min.	Typ.	Max.			
Diagnosis function in normal conditions							
Current sense settling time until IIS reached final value +/-3%	$t_{\mathrm{sIS(IN\_ON)}}$	–	800	1700	µs	$R_L = R_{L(NOM)}$	PRQ-169
Current sense settling time until IIS reached final value +/-3% after activation of DEN	$t_{\mathrm{sIS(DEN\_ON)}}$	0	25	85	µs	$V_S - V_{IS} \geq 5V$ $R_L = R_{L(NOM)}$	PRQ-172
Current sense disable time	$t_{\mathrm{sIS(DEN\_OFF)}}$	0	10	20	µs	From DEN falling edge to $I_{IS} = I_{IS(OFF)}$	PRQ-173
Current sense settling time after load change	$t_{\mathrm{sIS(LC)}}$	–	40	–	µs	[1] $I_L \geq I_{L0(MAX)}$	PRQ-174
IIS leakage current when IN disabled	$I_{\mathrm{IS(OFF)}}$	–	–	1	µA	$V_{IN} < V_{I(L)}$ R_{IS} = 2 kΩ $T_J \leq 150°C$	PRQ-175
Diagnosis function in overload condition							
Sense signal current in fault condition	$I_{\mathrm{IS(FAULT)}}$	2.3	3.0	5.2	mA	$(V_S - V_{IS}) \geq 5$ V Typical value for $V_S - V_{IS} \geq Min(V_S - V_{IS})$	PRQ-176
Fault propagation time for over temperature detection	$t_{\mathrm{pIS(FAULT\_OT)}}$	–	2.0	3.3	ms	[1]	PRQ-178
Delay time to reset fault pin after turning off VIN	$t_{\mathrm{IN(RESETDELAY)}}$	0.006	–	10	ms	–	PRQ-179
Diagnosis function: open load detection in off							
Open load detection threshold in off state voltage control	$V_{\mathrm{OUT(OL\_OFF)}}$	2.5	3	3.5	V	$V_{IN} < V_{I(L)}$ and $V_{DEN} > V_{I(H)}$	PRQ-180
Fault propagation time for open load detection off during turn off	$t_{\mathrm{pFAULT\_OL(IN\_OFF)}}$	–	5	20	µs	From falling edge on V_{IN} to $I_{S(FAULT)}$ on IS pin $V_{DEN} > V_{I(H)}$ $V_{OUT} > V_{OUT(OL\_OFF)}$	PRQ-181
Fault propagation time for open load detection off after activation of DEN	$t_{\mathrm{pFAULT\_OL(DEN\_ON)}}$	–	5	20	µs	From rising edge on V_{DEN} to $I_{IS(FAULT)}$ on IS pin $V_{IN} < V_{I(L)}$ $V_{OUT} > V_{OUT(OL\_OFF)}$	PRQ-182

(table continues...)

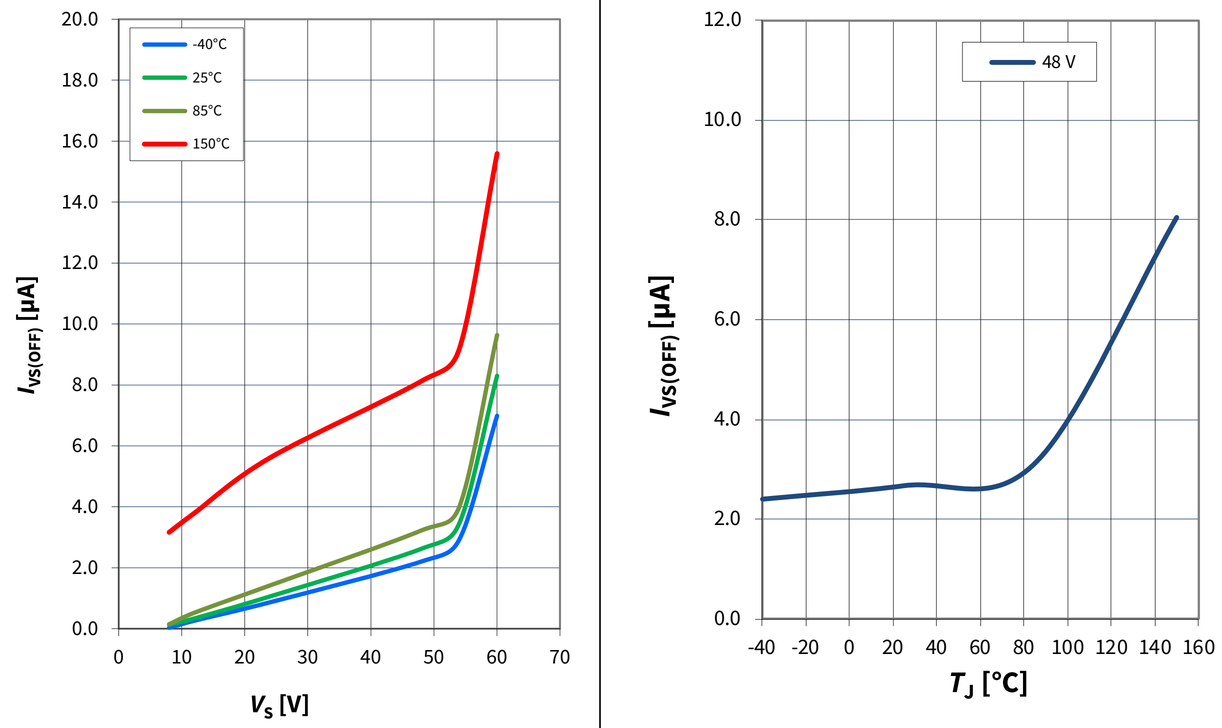
Table 6 (continued) Electrical characteristics table

V_S = 12 V to 54 V, T_J = -40°C to +150°C unless otherwise specified. For a given temperature or voltage range, typical values are specified at V_S = 48 V, T_J = 25°C.

Parameter	Symbol	Values			Unit	Note or condition	P-Number
		Min.	Typ.	Max.			
Disable time of IIS(FAULT) in off condition after desactivation of DEN	$t_{pFAULT\_OL(DEN\_OFF)}$	–	5	20	µs	From falling edge on V_{DEN} to $I_{IS(OFF)}$ on IS pin $V_{IN} < V_{I(L)}$	PRQ-183

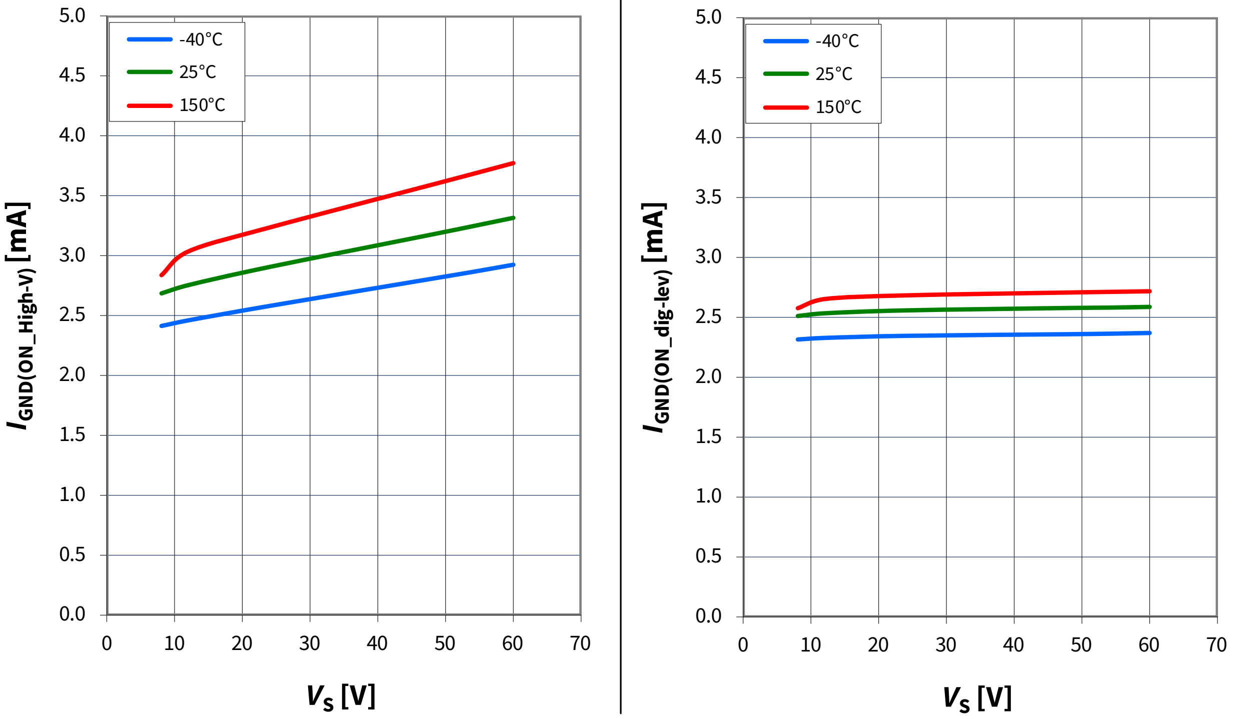
1) Not subject to production test, specified by design.

6 Typical performance characteristics



Standby current for whole device with load, $I_{VS(OFF)} = f(V_S, T_J)$

Standby current for whole device with load, $I_{VS(OFF)} = f(T_J)$, at $V_S = 48$ V

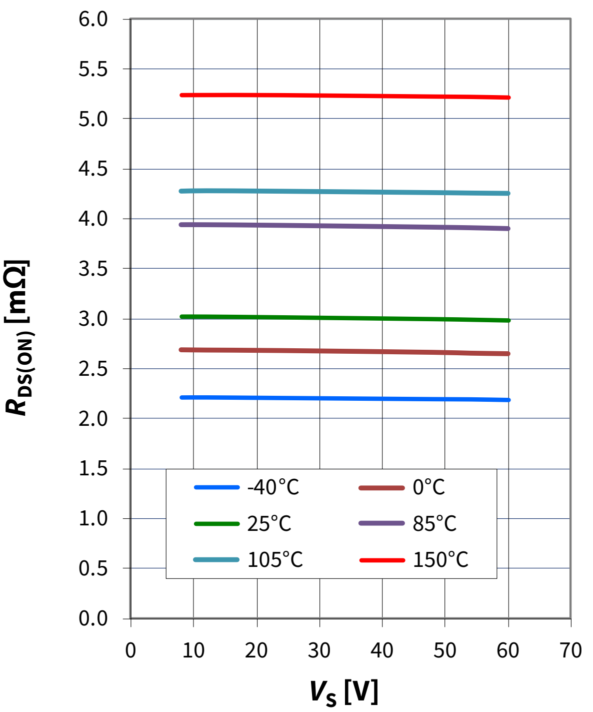


GND current when IN and DEN are biased to VS, $I_{GND(ON\_High\text{-}V)} = f(V_S, T_J)$

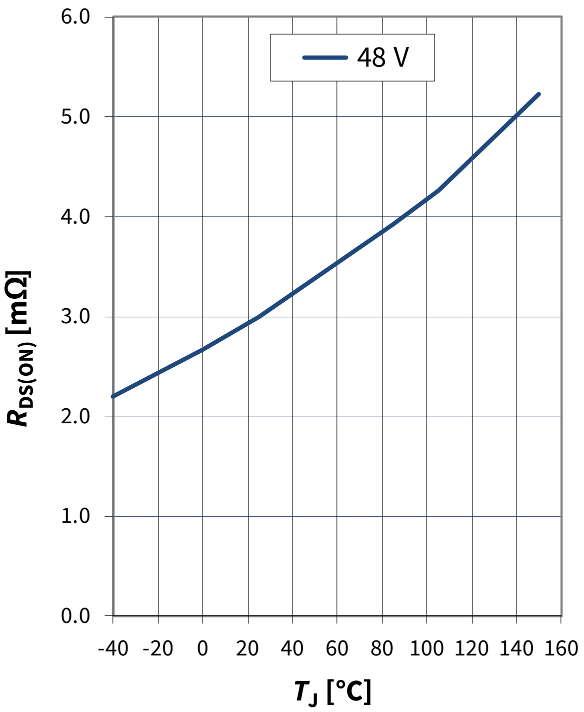
GND current when IN and DEN are biased to 5.5 V, $I_{GND(ON\_dig\text{-}lev)} = f(V_S, T_J)$

Figure 25 Typical performance characteristics

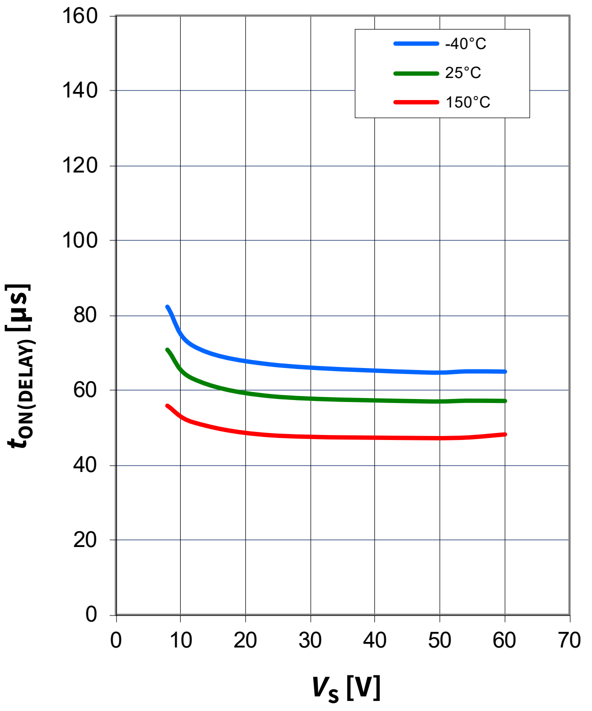
On state resistance at $I_L = 35$ A
$R_{DS(ON)} = f(V_S, T_J)$



On state resistance at $I_L = 35$ A and $V_S = 48$ V
$R_{DS(ON)} = f(T_J)$



Turn on time
$t_{ON(DELAY)} = f(V_S, T_J)$, $R_L = 2.5\ \Omega$



Turn off time
$t_{OFF(DELAY)} = f(V_S, T_J)$, $R_L = 2.5\ \Omega$

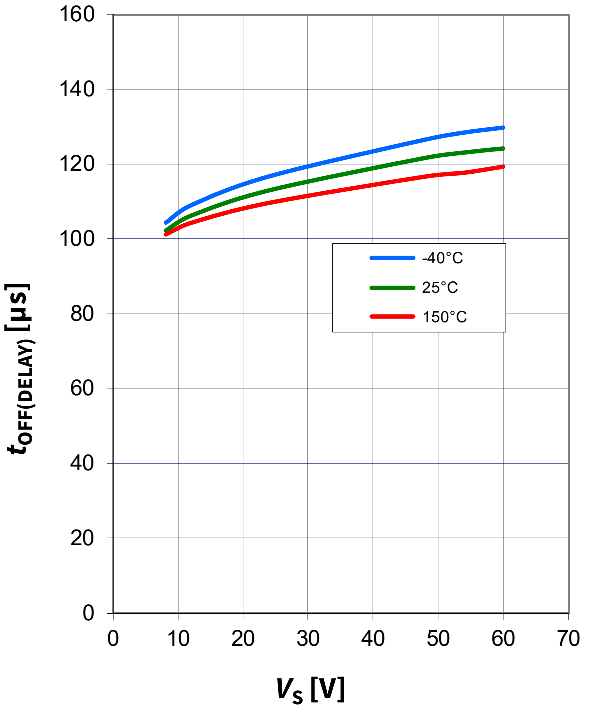
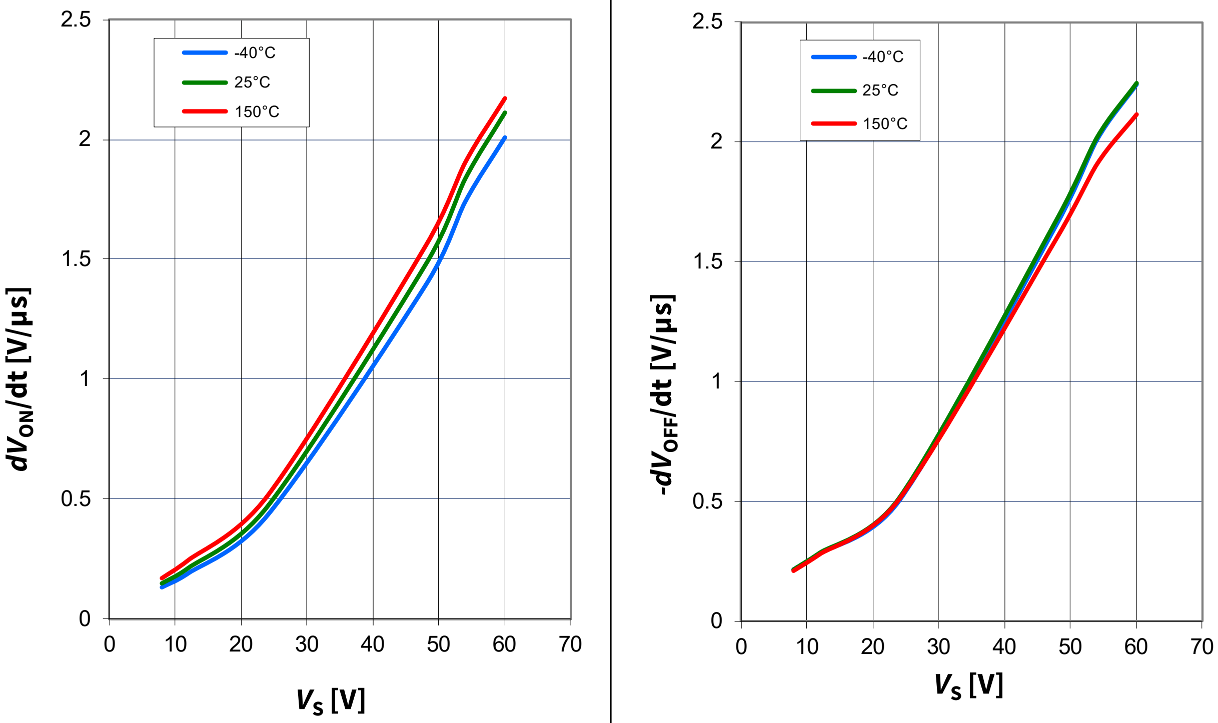


Figure 26 **Typical performance characteristics (continued)**

Slew rate at turn on
$dV_{ON/dt}$ = f(V_S, T_J), R_L = 2.5 Ω

Slew rate at turn off
-$dV_{OFF/dt}$ = f(V_S, T_J), R_L = 2.5 Ω



Energy at turn on
E_{ON} = f(V_S, T_J), R_L = 2.5 Ω

Energy at turn off
E_{OFF} = f(V_S, T_J), R_L = 2.5 Ω

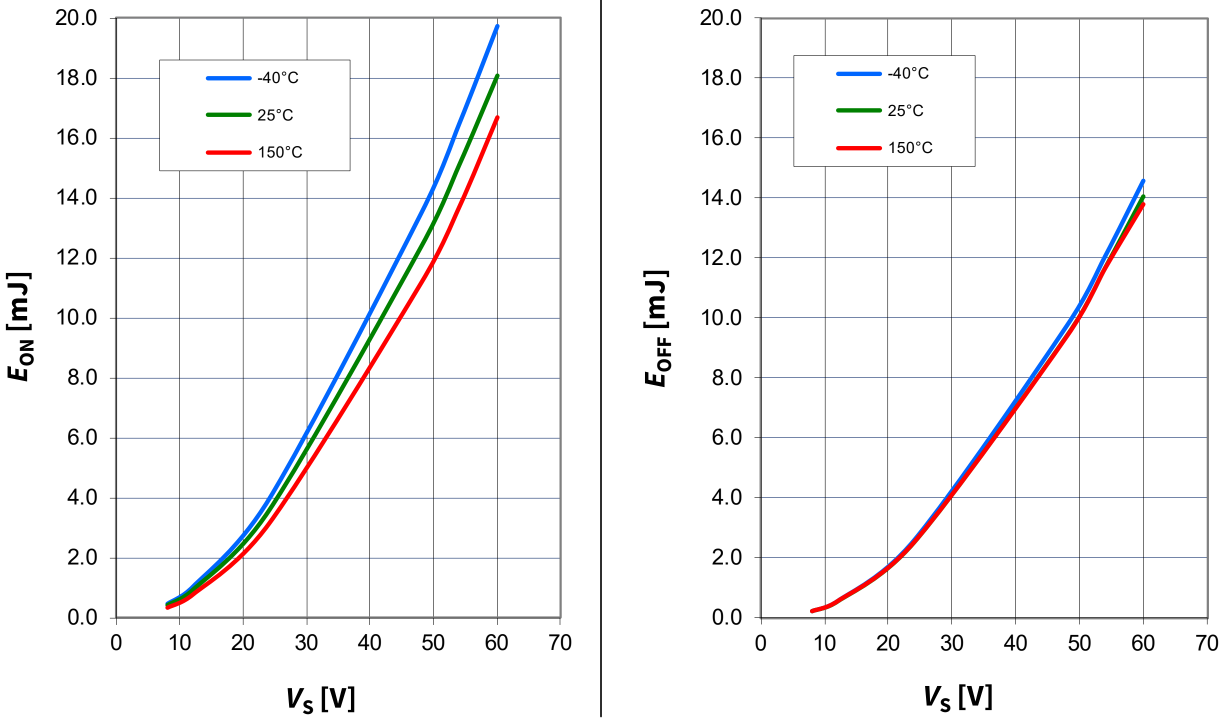
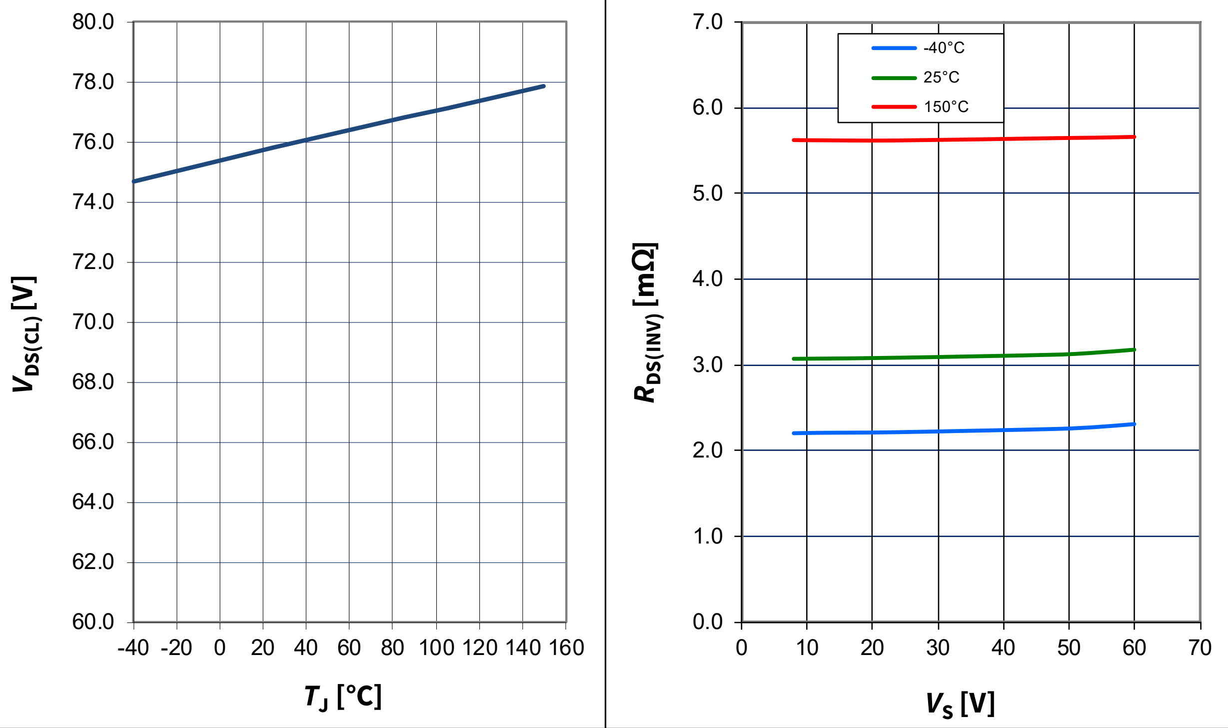
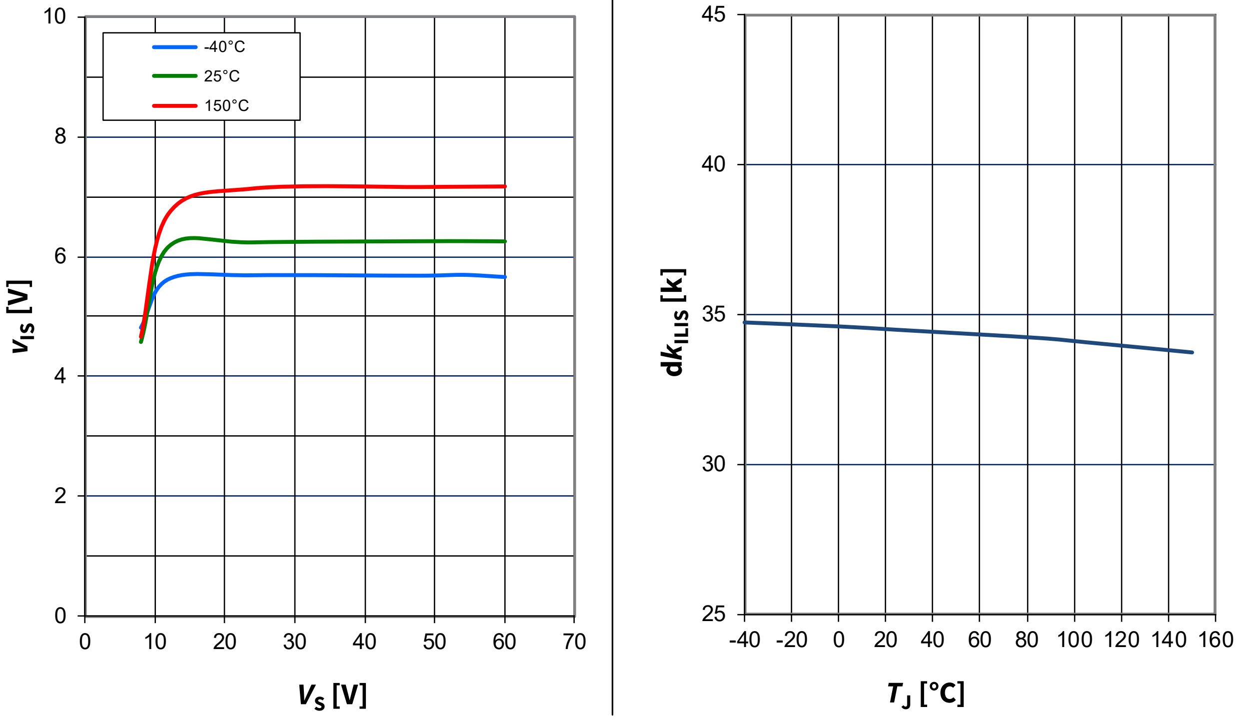


Figure 27 Typical performance characteristics (continued)



Drain to source smart clamp voltage
$V_{DS(CL)}$ = f(T_J)

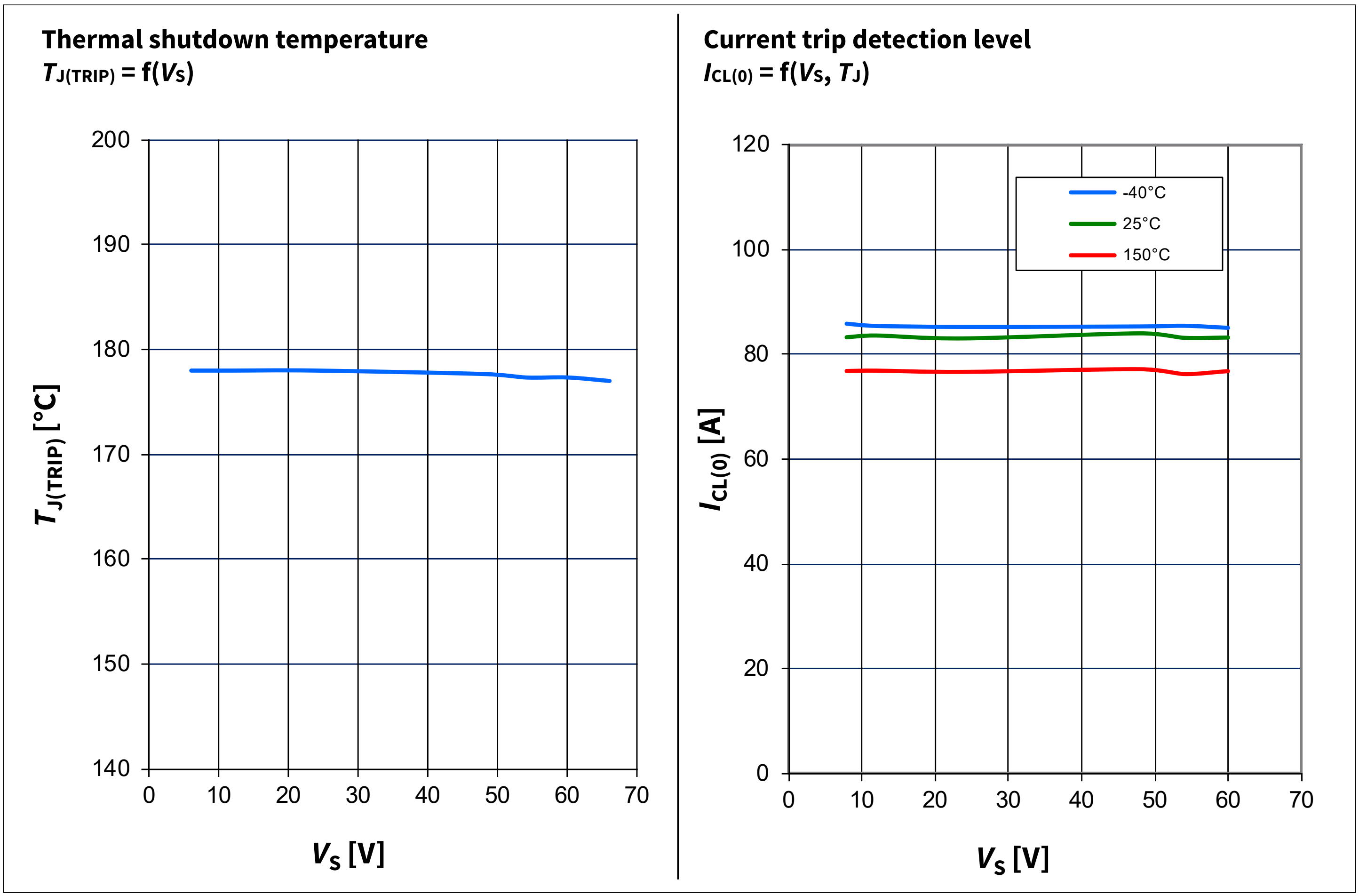
On resistance in inverse at I_L = -35 A
$R_{DS(INV)}$ = f(V_S, T_J)



Voltage on IS in fault
V_{IS} = f(V_S, T_J), R_{IS} = 2.0 kΩ

Current sense differential ratio
dk_{ILIS} = f(T_J)

Figure 28 **Typical performance characteristics (continued)**



Thermal shutdown temperature
$T_{J(TRIP)} = f(V_S)$

Current trip detection level
$I_{CL(0)} = f(V_S, T_J)$

Figure 29 **Typical performance characteristics (continued)**

7 Application information

Note: *The following information is given as a hint for the implementation of the device only and shall not be regarded as a description or warranty of a certain functionality, condition or quality of the device. These are very simplified examples of an application circuit. The function must be verified in the real application.*

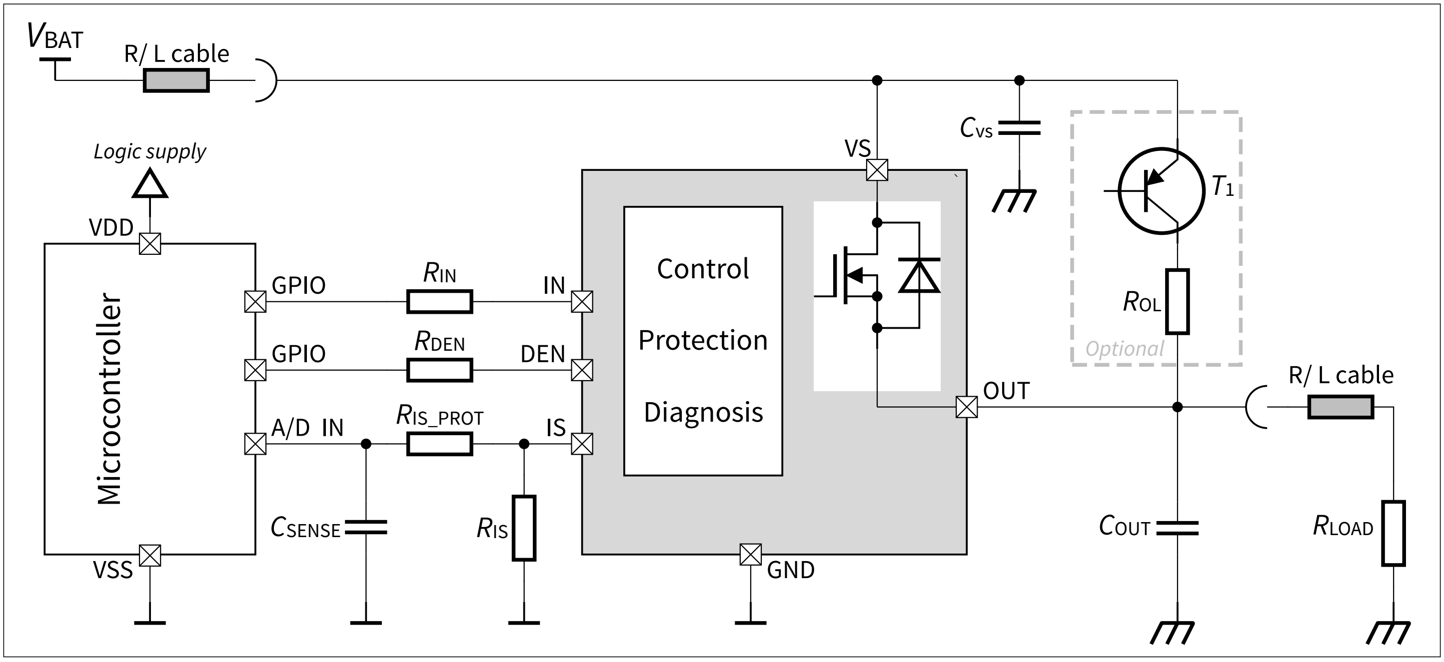


Figure 30 **Application diagram: device controlled by a microcontroller**

Table 7 **Bill of material**

Reference	Value	Purpose
R_{IN}	4.7 kΩ	Protection of the microcontroller
R_{DEN}	4.7 kΩ	Protection of the microcontroller
R_{IS}	2.0 kΩ	Sense resistor
R_{IS_PROT}	4.7 kΩ	Protection of the microcontroller
C_{SENSE}	10 nF	Sense signal filtering
C_{VS}	100 nF	Improved EMC behavior (in layout, please place close to the pins)
C_{OUT}	47 nF	Protection against EMC
R_{OL}	Application specific	Open load detection in off state: to have V_{OUT} higher than $V_{OUT(OL\_OFF)}$. The value depends on the leakage outside the ECU between OUT and GND

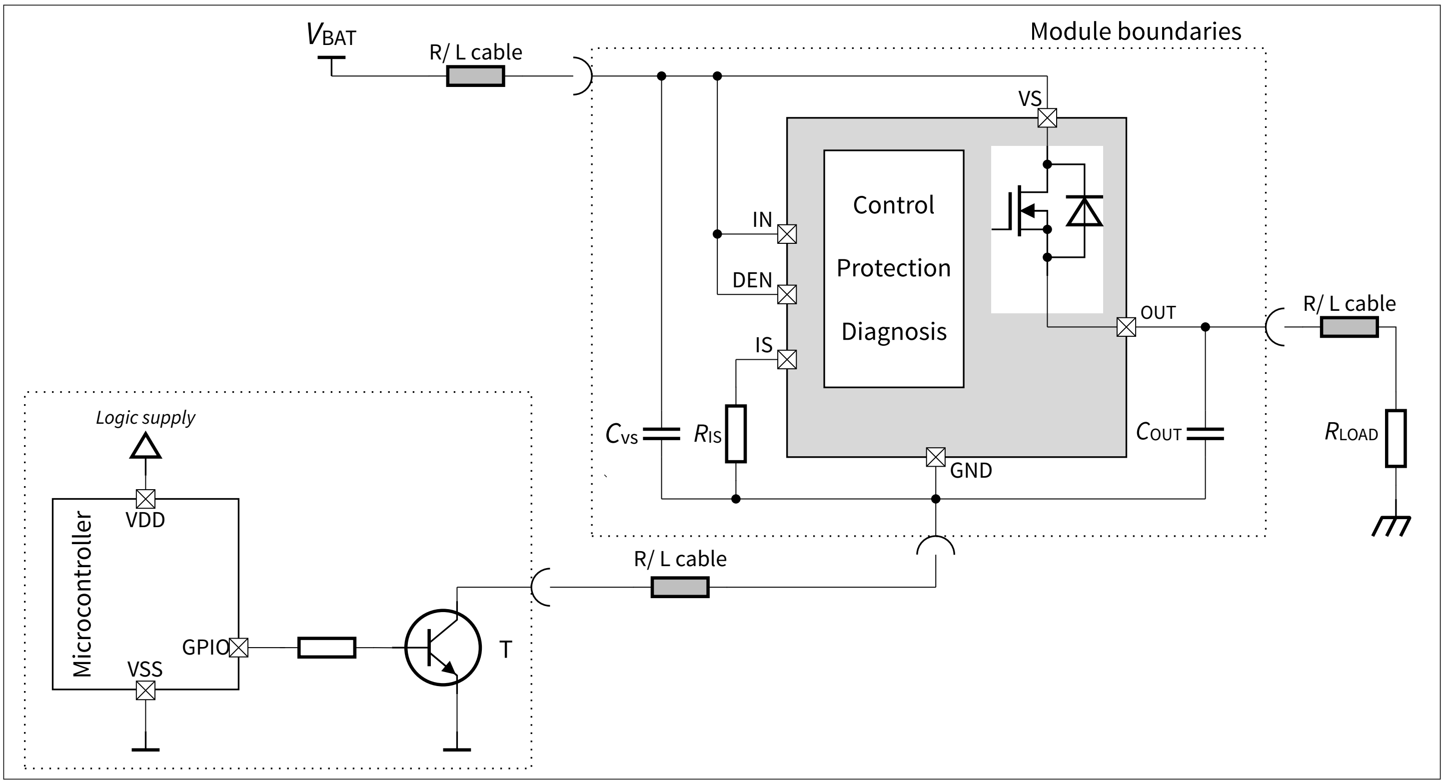


Figure 31 Application diagram: solid state relay for direct relay replacement

Table 8 Bill of material

Reference	Value	Purpose
R_{IS}	2.0 kΩ	Sense resistor
C_{VS}	100 nF	Improved EMC behavior (in layout, please place close to the pins)
C_{OUT}	47 nF	Protection against EMC
T	Bipolar or MOSFET	Switch to turn on and off the device

8 Package information

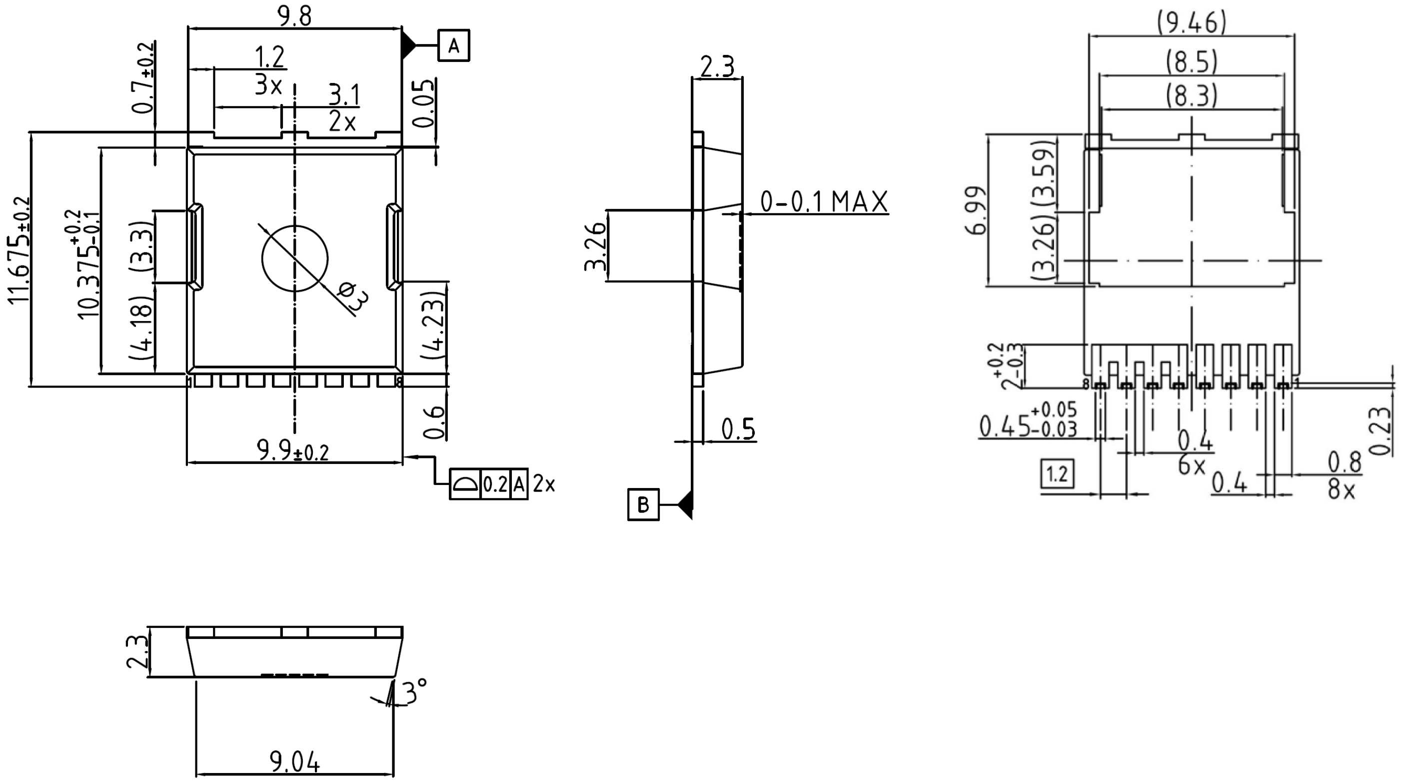


Figure 32 PG-HSOF-8 (8-pin TO-Leadless) package dimensions

Green Product (RoHS compliant) To meet the world-wide customer requirements for environmentally friendly products and to be compliant with government regulations the device is available as a green product. Green products are RoHS-Compliant (i.e Pb-free finish on leads and suitable for Pb-free soldering according to IPC/JEDEC J-STD-020).

9 Revision history

Revision	Date	Changes
1.00	2023-09-15	Datasheet released
1.01	2024-03-21	Maximum value of the PRQ-93, $I_{OUT(OFF)}$, changed from 100 µA to 50 µA
1.10	2024-12-03	• Note and condition of the PRQ-34 changed to "1) Short term overvoltage according to ISO 21780:2020(E), test-03 $R_L = R_{L(NOM)}$, $R_{IS} = 2\ k\Omega$" • Note and condition of the PRQ-55 changed to "1) 2) Parameter deviation possible, long term overvoltage according to ISO 21780:2020(E), test-06"

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