

# PROFET™ +24 V

**BTT6010-1ERB**

**Smart High-Side Power Switch, Single Channel 10 mΩ**

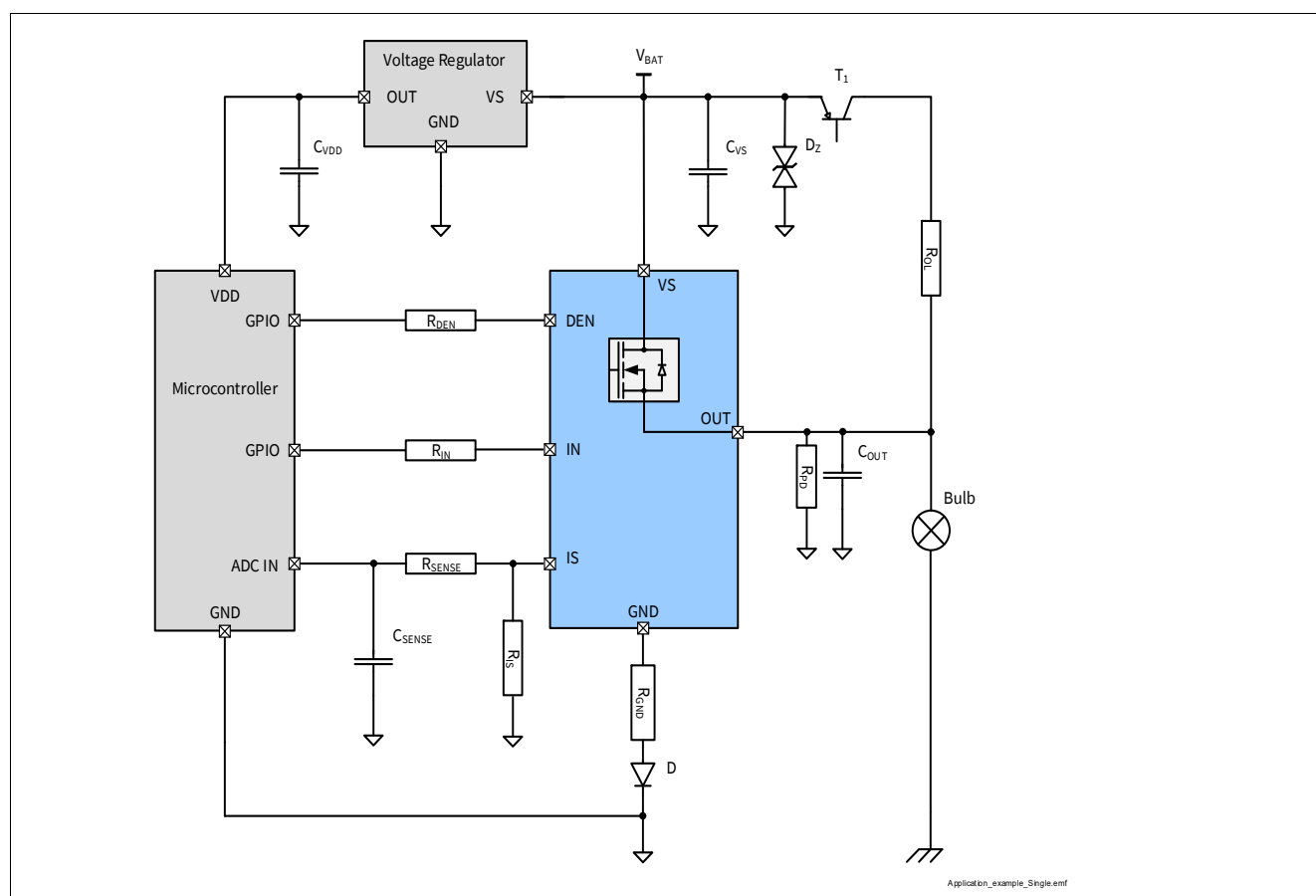
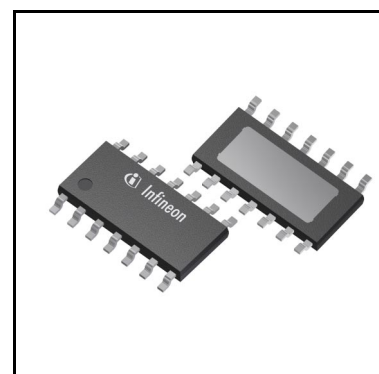


|                |            |
|----------------|------------|
| <b>Package</b> | PG-TDSO-14 |
| <b>Marking</b> | 6010-1ERB  |

## 1 Overview

### Application

- Suitable for resistive, inductive and capacitive loads
- Replaces electromechanical relays, fuses and discrete circuits
- Most suitable for loads with high inrush current, such as lamps
- Suitable for 12 V and 24 V truck and transportation system



**Application Diagram with BTT6010-1ERB**

## Overview

### Basic Features

- One channel device
- Very low stand-by current
- 3.3 V and 5 V compatible logic inputs
- Electrostatic discharge protection (ESD)
- Optimized electromagnetic compatibility
- Logic ground independent of load ground
- Very low power DMOS leakage current in OFF state
- Green product (RoHS compliant) and AEC qualified

### Description

The BTT6010-1ERB is a 10 mΩ single channel Smart High-Side Power Switch, embedded in a PG-TDSO-14, Exposed Pad package, providing protective functions and diagnosis. The power transistor is built by an N-channel vertical power MOSFET with charge pump. The device is integrated in Smart6 technology. It is specially designed to drive lamps up to 5 x P21W 24V or 1x H55W 12V, as well as LEDs in the harsh automotive environment.

**Table 1 Product Summary**

| Parameter                                                       | Symbol       | Value        |
|-----------------------------------------------------------------|--------------|--------------|
| Operating voltage range                                         | $V_{S(OP)}$  | 5 V ... 36 V |
| Maximum supply voltage                                          | $V_{S(LD)}$  | 66 V         |
| Maximum ON state resistance at $T_J = 150^{\circ}\text{C}$      | $R_{DS(ON)}$ | 22 mΩ        |
| Nominal load current                                            | $I_{L(NOM)}$ | 9 A          |
| Typical current sense ratio                                     | $k_{ILIS}$   | 3900         |
| Minimum current limitation                                      | $I_{LS(SC)}$ | 68 A         |
| Maximum standby current with load at $T_J = 25^{\circ}\text{C}$ | $I_{S(OFF)}$ | 1.4 μA       |

### Diagnostic Functions

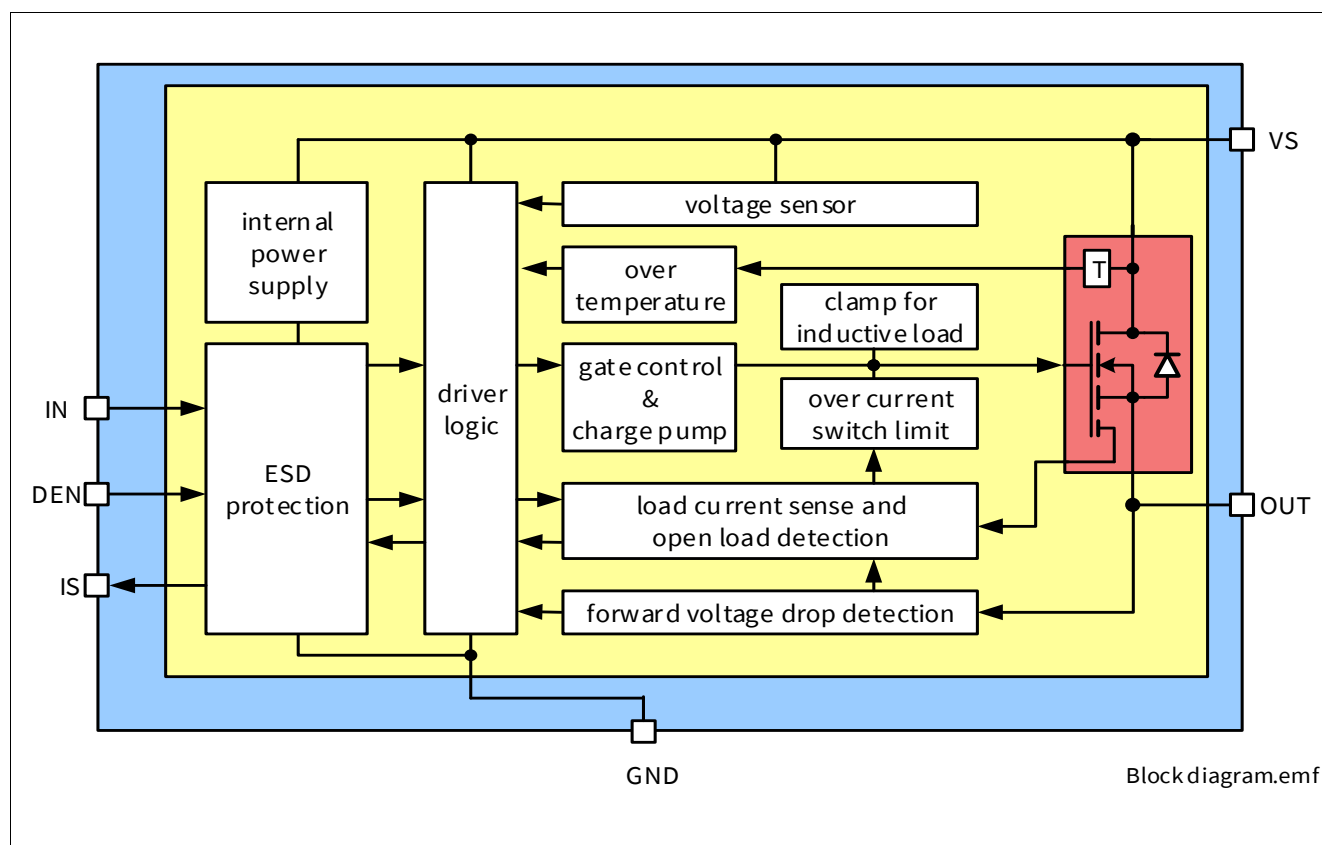
- Proportional load current sense
- Open load in ON and OFF
- Short circuit to battery and ground
- Overtemperature
- Stable diagnostic signal during short circuit
- Enhanced  $k_{ILIS}$  dependency with temperature and load current

### Protection Functions

- Stable behavior during undervoltage
- Reverse polarity protection with external components
- Secure load turn-off during logic ground disconnect with external components
- Overtemperature protection with latch
- Overvoltage protection with external components
- Voltage dependent current limitation
- Enhanced short circuit operation for up to 40 m cables

## Block Diagram

### 2 Block Diagram



**Figure 1 Block Diagram for the BTT6010-1ERB**

### 3 Pin Configuration

#### 3.1 Pin Assignment

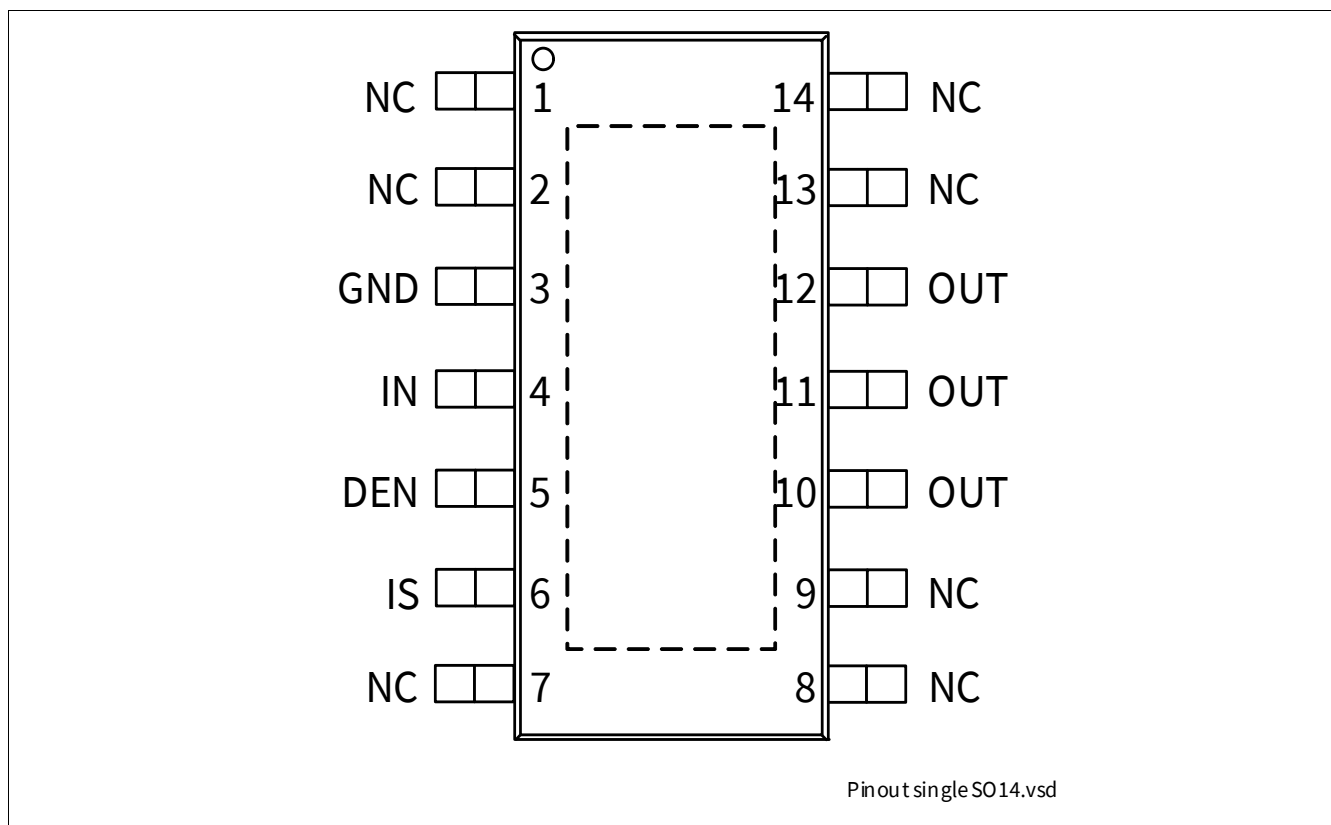


Figure 2 Pin Configuration

#### 3.2 Pin Definitions and Functions

Table 2 Pin Definitions and Functions

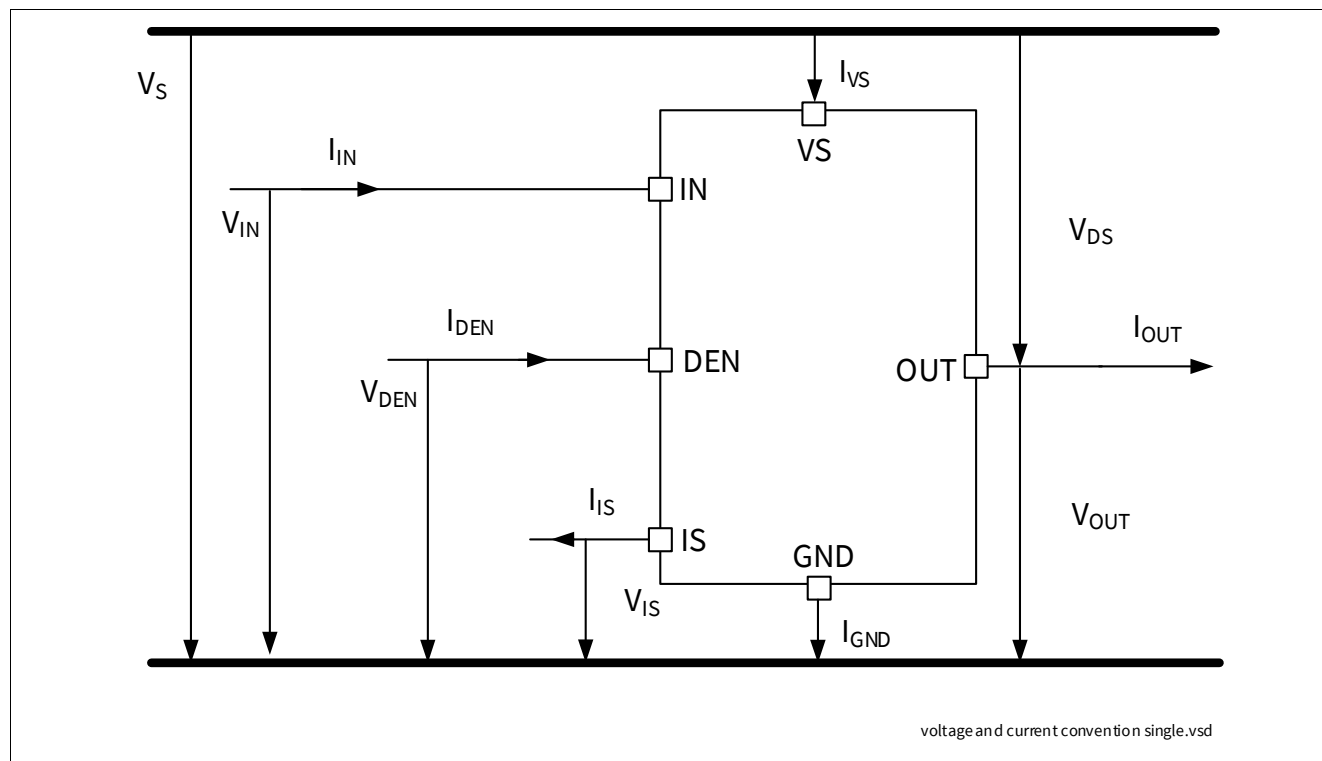
| Pin                   | Symbol | Function                                                                               |
|-----------------------|--------|----------------------------------------------------------------------------------------|
| Cooling Tab           | VS     | <b>Voltage Supply;</b> Battery voltage                                                 |
| 1, 2, 7, 8, 9, 13, 14 | NC     | <b>Not Connected;</b> No internal connection to the chip                               |
| 3                     | GND    | <b>GrouND;</b> Ground connection                                                       |
| 4                     | IN     | <b>INput channel;</b> Input signal for channel activation                              |
| 5                     | DEN    | <b>Diagnostic ENable;</b> Digital signal to enable/disable the diagnosis of the device |
| 6                     | IS     | <b>Sense;</b> Sense current of the selected channel                                    |
| 10, 11, 12            | OUT    | <b>OUTput;</b> Protected high side power output channel <sup>1)</sup>                  |

1) All output pins must be connected together on the PCB. All pins of the output are internally connected together. PCB traces have to be designed to withstand the maximum current which can flow.

## Pin Configuration

### 3.3 Voltage and Current Definition

**Figure 3** shows all terms used in this data sheet, with associated convention for positive values.



**Figure 3 Voltage and Current Definition**

## 4 General Product Characteristics

### 4.1 Absolute Maximum Ratings

**Table 3 Absolute Maximum Ratings** <sup>1)</sup>

$T_J = -40^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$ ; (unless otherwise specified)

| Parameter                                   | Symbol               | Values    |      |                     | Unit     | Note or Test Condition                                                                                                                                                                                                                                                                               | Number   |
|---------------------------------------------|----------------------|-----------|------|---------------------|----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
|                                             |                      | Min.      | Typ. | Max.                |          |                                                                                                                                                                                                                                                                                                      |          |
| Supply Voltages                             |                      |           |      |                     |          |                                                                                                                                                                                                                                                                                                      |          |
| Supply voltage                              | $V_S$                | -0.3      | –    | 48                  | V        | –                                                                                                                                                                                                                                                                                                    | P_4.1.1  |
| Reverse polarity voltage                    | $-V_{S(\text{REV})}$ | 0         | –    | 28                  | V        | $t < 2 \text{ min}$<br>$T_A = 25^{\circ}\text{C}$<br>$R_L \geq 4 \Omega$                                                                                                                                                                                                                             | P_4.1.2  |
| Supply voltage for short circuit protection | $V_{\text{BAT(SC)}}$ | 0         | –    | 36                  | V        | $R_{\text{supply}} = 10 \text{ m}\Omega$<br>$L_{\text{supply}} = 5 \mu\text{H}$<br>$R_{\text{Cable1}} = 20 \text{ m}\Omega$<br>$L_{\text{Cable1}} = 0 \mu\text{H}$<br>$R_{\text{Cable2}} = 320 \text{ m}\Omega$<br>$L_{\text{Cable2}} = 40 \mu\text{H}$<br>See <b>Chapter 6</b> and <b>Figure 29</b> | P_4.1.3  |
| Supply voltage for Load dump protection     | $V_{S(\text{LD})}$   | –         | –    | 66                  | V        | <sup>2)</sup> $R_I = 2 \Omega$<br>$R_L = 4 \Omega$                                                                                                                                                                                                                                                   | P_4.1.12 |
| Short Circuit Capability                    |                      |           |      |                     |          |                                                                                                                                                                                                                                                                                                      |          |
| Permanent short circuit IN pin toggles      | $n_{\text{RSC1}}$    |           | –    | 100                 | k cycles | <sup>3)</sup> $V_{\text{supply}} = 28 \text{ V}$                                                                                                                                                                                                                                                     | P_4.1.4  |
| Input Pins                                  |                      |           |      |                     |          |                                                                                                                                                                                                                                                                                                      |          |
| Voltage at INPUT pin                        | $V_{\text{IN}}$      | -0.3<br>– | –    | 6<br>7              | V        | –<br>$t < 2 \text{ min}$                                                                                                                                                                                                                                                                             | P_4.1.13 |
| Current through INPUT pin                   | $I_{\text{IN}}$      | -2        | –    | 2                   | mA       | –                                                                                                                                                                                                                                                                                                    | P_4.1.14 |
| Voltage at DEN pin                          | $V_{\text{DEN}}$     | -0.3<br>– | –    | 6<br>7              | V        | –<br>$t < 2 \text{ min}$                                                                                                                                                                                                                                                                             | P_4.1.15 |
| Current through DEN pin                     | $I_{\text{DEN}}$     | -2        | –    | 2                   | mA       | –                                                                                                                                                                                                                                                                                                    | P_4.1.16 |
| Sense Pin                                   |                      |           |      |                     |          |                                                                                                                                                                                                                                                                                                      |          |
| Voltage at IS pin                           | $V_{\text{IS}}$      | -0.3      | –    | $V_S$               | V        | –                                                                                                                                                                                                                                                                                                    | P_4.1.19 |
| Current through IS pin                      | $I_{\text{IS}}$      | -25       | –    | 50                  | mA       | –                                                                                                                                                                                                                                                                                                    | P_4.1.20 |
| Power Stage                                 |                      |           |      |                     |          |                                                                                                                                                                                                                                                                                                      |          |
| Load current                                | $ I_L $              | –         | –    | $I_{L(\text{LIM})}$ | A        | –                                                                                                                                                                                                                                                                                                    | P_4.1.21 |
| Power dissipation (DC)                      | $P_{\text{TOT}}$     | –         | –    | 1.6                 | W        | $T_A = 85^{\circ}\text{C}$<br>$T_J < 150^{\circ}\text{C}$                                                                                                                                                                                                                                            | P_4.1.22 |

**General Product Characteristics**

**Table 3 Absolute Maximum Ratings (cont'd)<sup>1)</sup>**

$T_J = -40^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$ ; (unless otherwise specified)

| Parameter                                  | Symbol   | Values |      |      | Unit | Note or Test Condition                                                             | Number   |
|--------------------------------------------|----------|--------|------|------|------|------------------------------------------------------------------------------------|----------|
|                                            |          | Min.   | Typ. | Max. |      |                                                                                    |          |
| Maximum energy dissipation<br>Single pulse | $E_{AS}$ | –      | –    | 219  | mJ   | $I_{L(0)} = 9\text{ A}$<br>$T_{J(0)} = 150^{\circ}\text{C}$<br>$V_S = 28\text{ V}$ | P_4.1.23 |
| Voltage at power transistor                | $V_{DS}$ | –      | –    | 66   | V    | –                                                                                  | P_4.1.26 |

**Currents**

|                            |           |             |   |          |    |                         |          |
|----------------------------|-----------|-------------|---|----------|----|-------------------------|----------|
| Current through ground pin | $I_{GND}$ | -20<br>-200 | – | 20<br>20 | mA | –<br>$t < 2\text{ min}$ | P_4.1.27 |
|----------------------------|-----------|-------------|---|----------|----|-------------------------|----------|

**Temperatures**

|                      |           |     |   |     |                    |   |          |
|----------------------|-----------|-----|---|-----|--------------------|---|----------|
| Junction temperature | $T_J$     | -40 | – | 150 | $^{\circ}\text{C}$ | – | P_4.1.28 |
| Storage temperature  | $T_{STG}$ | -55 | – | 150 | $^{\circ}\text{C}$ | – | P_4.1.30 |

**ESD Susceptibility**

|                                                        |           |      |   |     |    |                   |          |
|--------------------------------------------------------|-----------|------|---|-----|----|-------------------|----------|
| ESD susceptibility (all pins)                          | $V_{ESD}$ | -2   | – | 2   | kV | <sup>4)</sup> HBM | P_4.1.31 |
| ESD susceptibility OUT Pin<br>vs. GND and VS connected | $V_{ESD}$ | -4   | – | 4   | kV | <sup>4)</sup> HBM | P_4.1.32 |
| ESD susceptibility                                     | $V_{ESD}$ | -500 | – | 500 | V  | <sup>5)</sup> CDM | P_4.1.33 |
| ESD susceptibility pin<br>(corner pins)                | $V_{ESD}$ | -750 | – | 750 | V  | <sup>5)</sup> CDM | P_4.1.34 |

1) Not subject to production test. Specified by design

2)  $V_{S(LD)}$  is setup without the DUT connected to the generator per ISO 7637-1

3) Threshold limit for short circuit failures : 100ppm. Please refer to the legal disclaimer for short circuit capability on the Back Cover of this document

4) ESD susceptibility, Human Body Model “HBM” according to AEC Q100-002

5) ESD susceptibility, Charged Device Model “CDM” according to AEC Q100-011

**Notes**

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

**General Product Characteristics**

**4.2 Functional Range**

**Table 4 Functional Range  $T_J = -40^\circ\text{C}$  to  $+150^\circ\text{C}$ ; (unless otherwise specified)**

| Parameter                                                     | Symbol                   | Values |      |      | Unit          | Note or Test Condition                                                                                                                                                                                                                          | Number   |
|---------------------------------------------------------------|--------------------------|--------|------|------|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
|                                                               |                          | Min.   | Typ. | Max. |               |                                                                                                                                                                                                                                                 |          |
| Nominal operating voltage                                     | $V_{\text{NOM}}$         | 8      | 28   | 36   | V             | –                                                                                                                                                                                                                                               | P_4.2.1  |
| Extended operating voltage                                    | $V_{\text{S(OP)}}$       | 5      | –    | 48   | V             | <sup>2)</sup> $V_{\text{IN}} = 4.5\text{ V}$<br>$R_L = 4\ \Omega$<br>$V_{\text{DS}} < 0.5\text{ V}$<br>See <a href="#">Figure 15</a>                                                                                                            | P_4.2.2  |
| Minimum functional supply voltage                             | $V_{\text{S(OP)_MIN}}$   | 3.8    | 4.3  | 5    | V             | <sup>1)</sup> $V_{\text{IN}} = 4.5\text{ V}$<br>$R_L = 4\ \Omega$<br>From $I_{\text{OUT}} = 0\text{ A}$<br>to $V_{\text{DS}} < 0.5\text{ V}$ ;<br>See <a href="#">Figure 15</a>                                                                 | P_4.2.3  |
| Undervoltage shutdown                                         | $V_{\text{S(UV)}}$       | 3      | 3.5  | 4.1  | V             | <sup>1)</sup> $V_{\text{IN}} = 4.5\text{ V}$<br>$V_{\text{DEN}} = 0\text{ V}$<br>$R_L = 4\ \Omega$<br>From $V_{\text{DS}} < 1\text{ V}$ ;<br>to $I_{\text{OUT}} = 0\text{ A}$<br>See <a href="#">Figure 15</a><br>See <a href="#">Chapter 9</a> | P_4.2.4  |
| Undervoltage shutdown hysteresis                              | $V_{\text{S(UV)_HYS}}$   | –      | 850  | –    | mV            | <sup>2)</sup> –                                                                                                                                                                                                                                 | P_4.2.13 |
| Operating current channel active                              | $I_{\text{GND}_1}$       | –      | 4.8  | 9    | mA            | $V_{\text{IN}} = 5.5\text{ V}$<br>$V_{\text{DEN}} = 5.5\text{ V}$<br>Device in $R_{\text{DS(ON)}}$<br>$V_S = 36\text{ V}$<br>See <a href="#">Chapter 9</a>                                                                                      | P_4.2.5  |
| Standby current for whole device with load (ambient)          | $I_{\text{S(OFF)}}$      | –      | 0.1  | 0.5  | $\mu\text{A}$ | <sup>1)</sup> $V_S = 36\text{ V}$<br>$V_{\text{OUT}} = 0\text{ V}$<br>$V_{\text{IN}}$ floating<br>$V_{\text{DEN}}$ floating<br>$T_J \leq 85^\circ\text{C}$<br>See <a href="#">Chapter 9</a>                                                     | P_4.2.7  |
| Maximum standby current for whole device with load            | $I_{\text{S(OFF)_150}}$  | –      | 8    | 15   | $\mu\text{A}$ | $V_S = 36\text{ V}$<br>$V_{\text{OUT}} = 0\text{ V}$<br>$V_{\text{IN}}$ floating<br>$V_{\text{DEN}}$ floating<br>$T_J = 150^\circ\text{C}$<br>See <a href="#">Chapter 9</a>                                                                     | P_4.2.10 |
| Standby current for whole device with load, diagnostic active | $I_{\text{S(OFF\_DEN)}}$ | –      | 0.6  | –    | mA            | <sup>2)</sup> $V_S = 36\text{ V}$<br>$V_{\text{OUT}} = 0\text{ V}$<br>$V_{\text{IN}}$ floating<br>$V_{\text{DEN}} = 5.5\text{ V}$                                                                                                               | P_4.2.8  |

1) Test at  $T_J = -40^\circ\text{C}$  only

2) Not subject to production test. Specified by design.

## General Product Characteristics

*Note:* Within the functional range the IC operates as described in the circuit description. The electrical characteristics are specified within the conditions given in the related electrical characteristics table.

### 4.3 Thermal Resistance

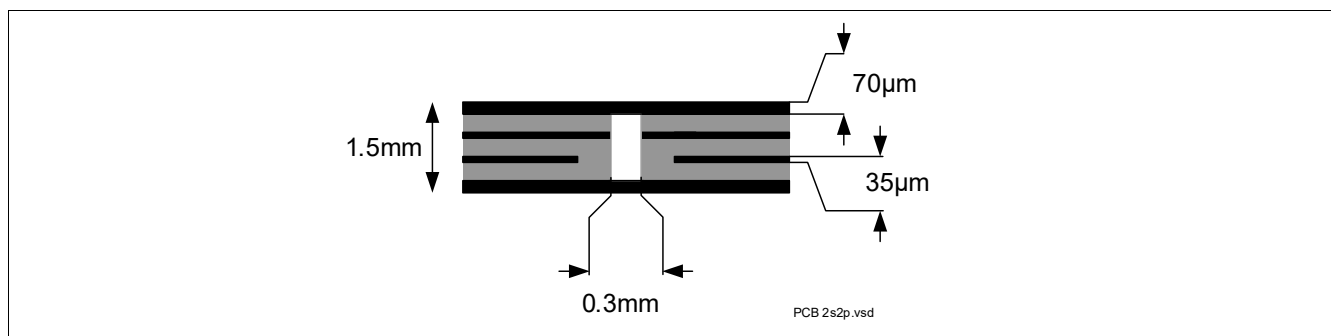
**Table 5 Thermal Resistance**

| Parameter           | Symbol     | Values |      |      | Unit | Note or Test Condition | Number  |
|---------------------|------------|--------|------|------|------|------------------------|---------|
|                     |            | Min.   | Typ. | Max. |      |                        |         |
| Junction to case    | $R_{thJC}$ | –      | 1    | –    | K/W  | 1)                     | P_4.3.1 |
| Junction to ambient | $R_{thJA}$ | –      | 25   | –    | K/W  | 1) 2)                  | P_4.3.2 |

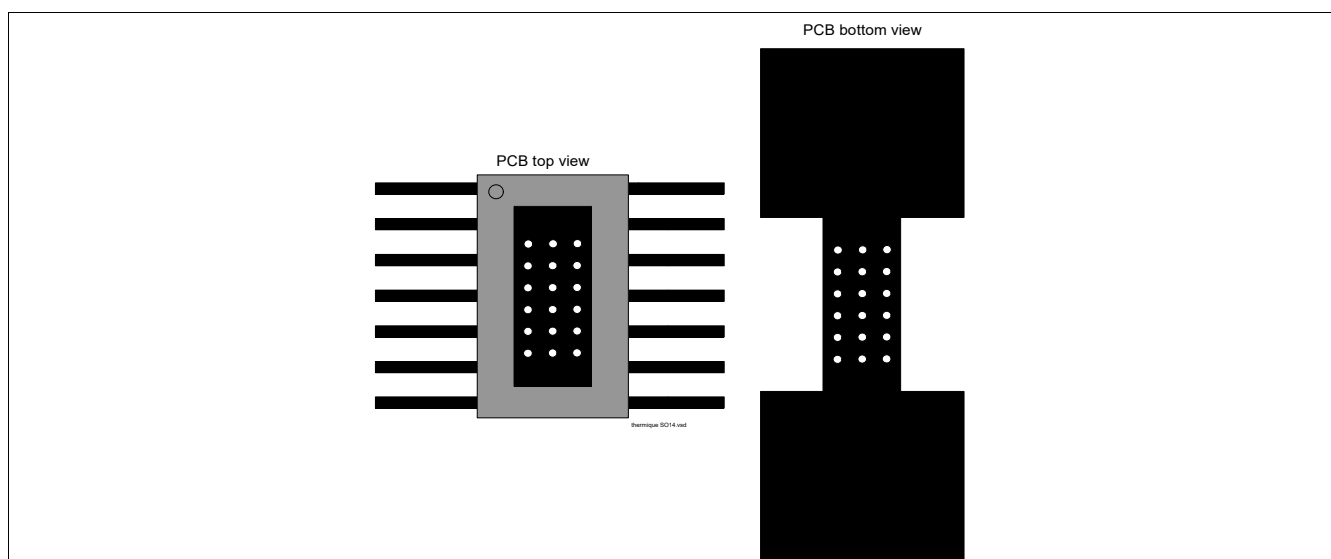
1) Not subject to production test. Specified by design.

2) Specified  $R_{thJA}$  value is according to JEDEC JESD51-2,-5,-7 at natural convection on FR4 2s2p board with 1 W total power dissipation at  $T_A=105^{\circ}\text{C}$ ; The product (chip + package) was simulated on a 76.4 x 114.3 x 1.5 mm board with 2 inner copper layers (2 x 70  $\mu\text{m}$  Cu, 2 x 35  $\mu\text{m}$  Cu). Where applicable, a thermal via array under the exposed pad contacts the first inner copper layer. Please refer to [Figure 4](#).

#### 4.3.1 PCB Set-Up



**Figure 4 2s2p PCB Cross Section**



**Figure 5 PC Board Top and Bottom View for Thermal Simulation with 600 mm² Cooling Area**

### 4.3.2 Thermal Impedance

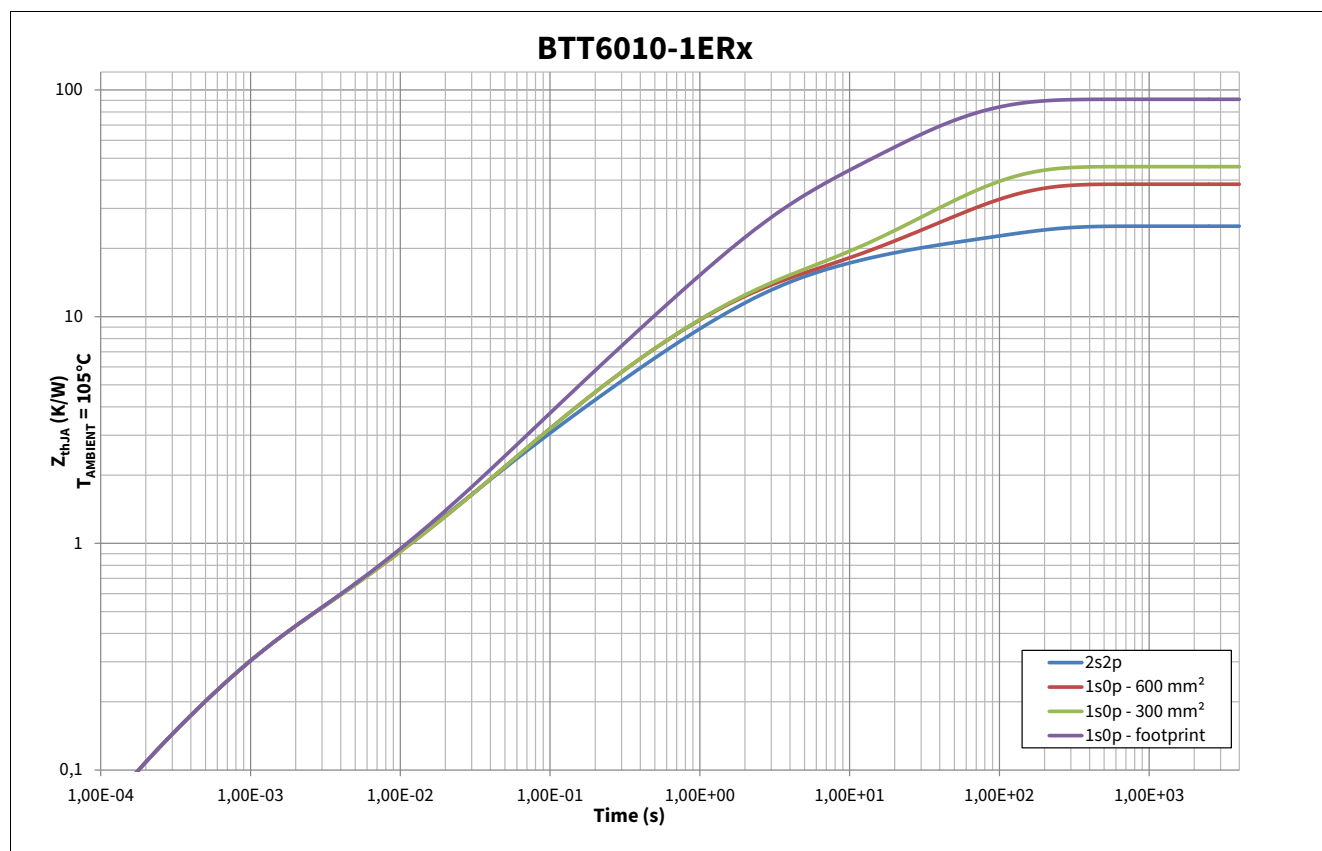


Figure 6 Typical Thermal Impedance. 2s2p PCB set-up according to Figure 4

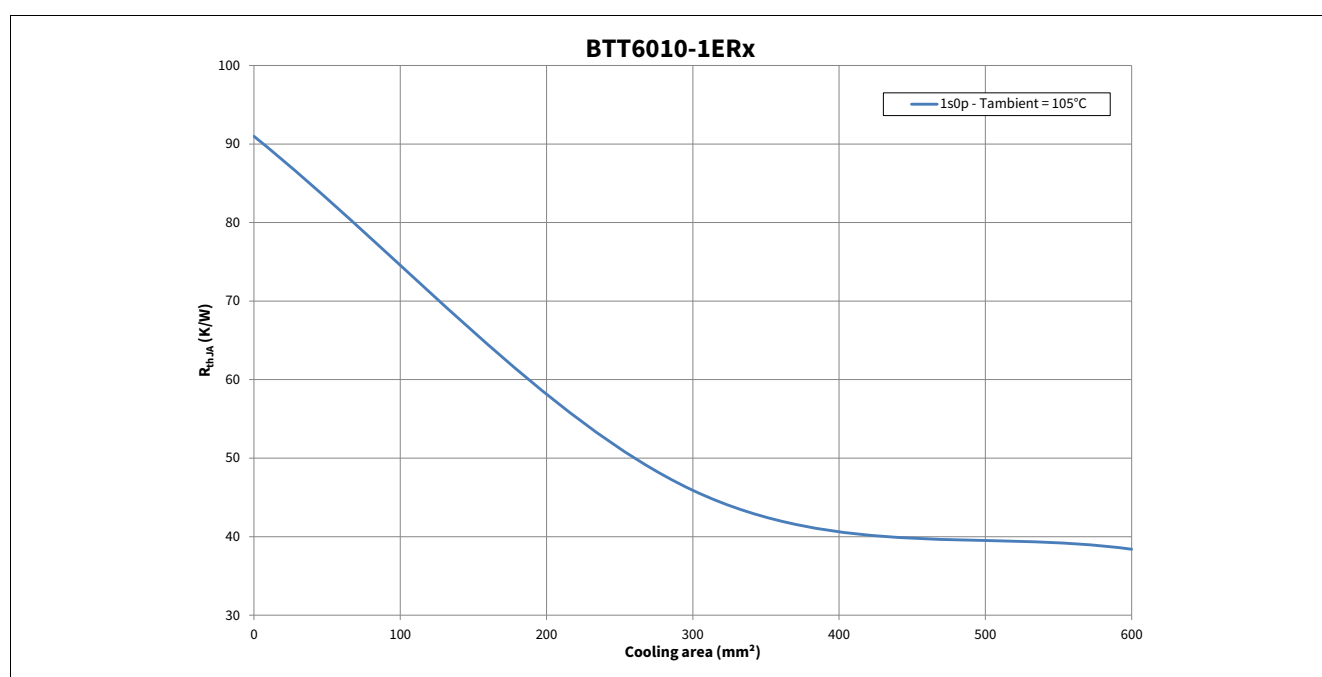


Figure 7 Typical Thermal Resistance. PCB set-up 1s0p

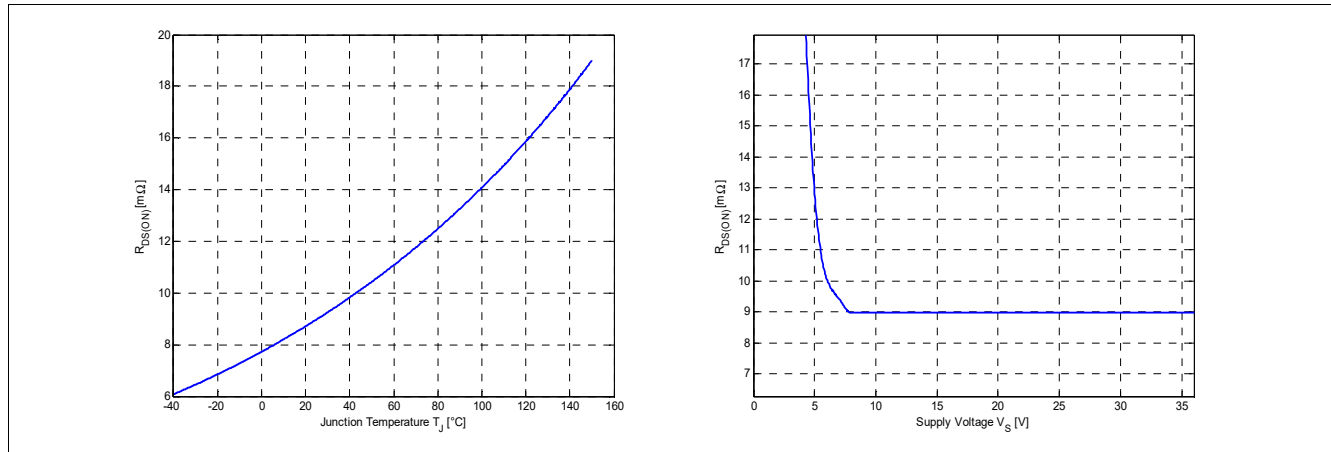
## Power Stage

### 5 Power Stage

The power stage is built using an N-channel vertical power MOSFET (DMOS) with charge pump.

#### 5.1 Output ON-State Resistance

The ON-state resistance  $R_{DS(ON)}$  depends on the supply voltage as well as the junction temperature  $T_J$ . **Figure 8** shows the dependencies in terms of temperature and supply voltage for the typical ON-state resistance. The behavior in reverse polarity is described in **Chapter 6.4**.

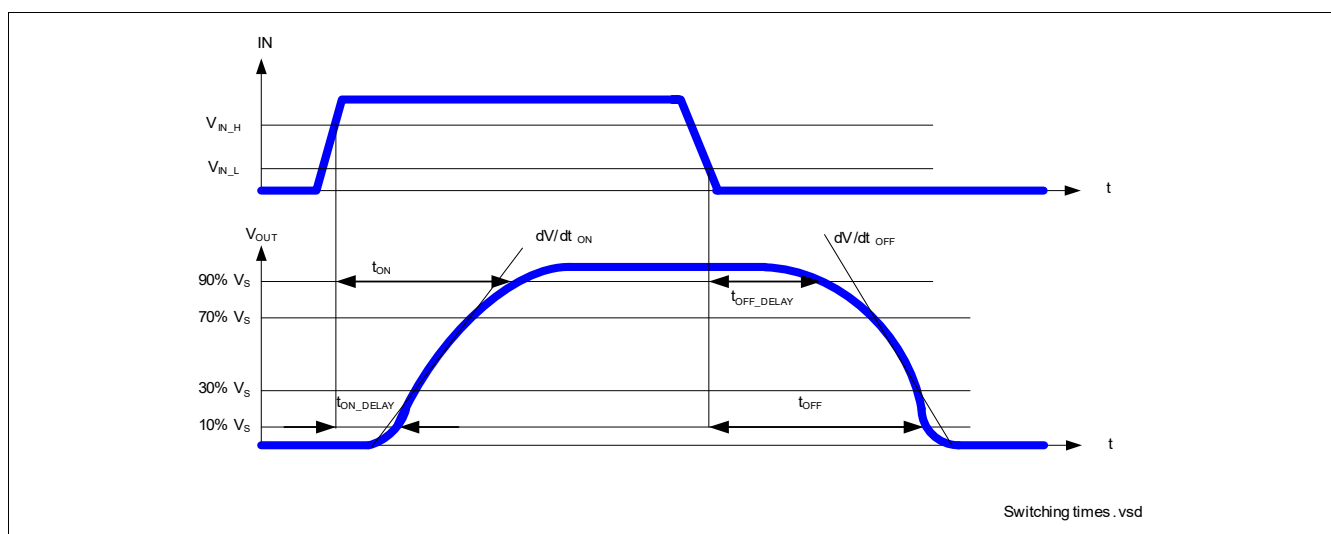


**Figure 8** Typical ON-State Resistance

A high signal (see **Chapter 8**) at the input pin causes the power DMOS to switch ON with a dedicated slope, which is optimized in terms of EMC emission.

#### 5.2 Turn ON/OFF Characteristics with Resistive Load

**Figure 9** shows the typical timing when switching a resistive load.



**Figure 9** Switching a Resistive Load Timing

## Power Stage

### 5.3 Inductive Load

#### 5.3.1 Output Clamping

When switching OFF inductive loads with high-side switches, the voltage  $V_{OUT}$  drops below ground potential, because the inductance intends to continue driving the current. To prevent the destruction of the device by avalanche due to high voltages, there is a voltage clamp mechanism  $Z_{DS(AZ)}$  implemented that limits negative output voltage to a certain level ( $V_S - V_{DS(AZ)}$ ). Please refer to [Figure 10](#) and [Figure 11](#) for details. Nevertheless, the maximum allowed load inductance is limited.

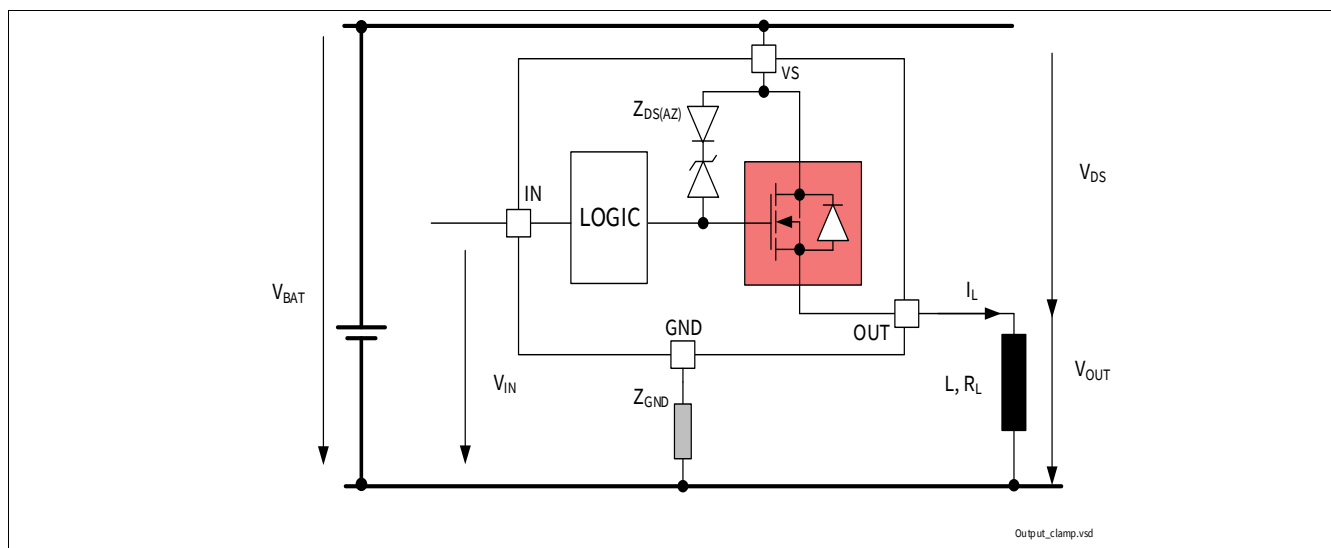


Figure 10 Output Clamp

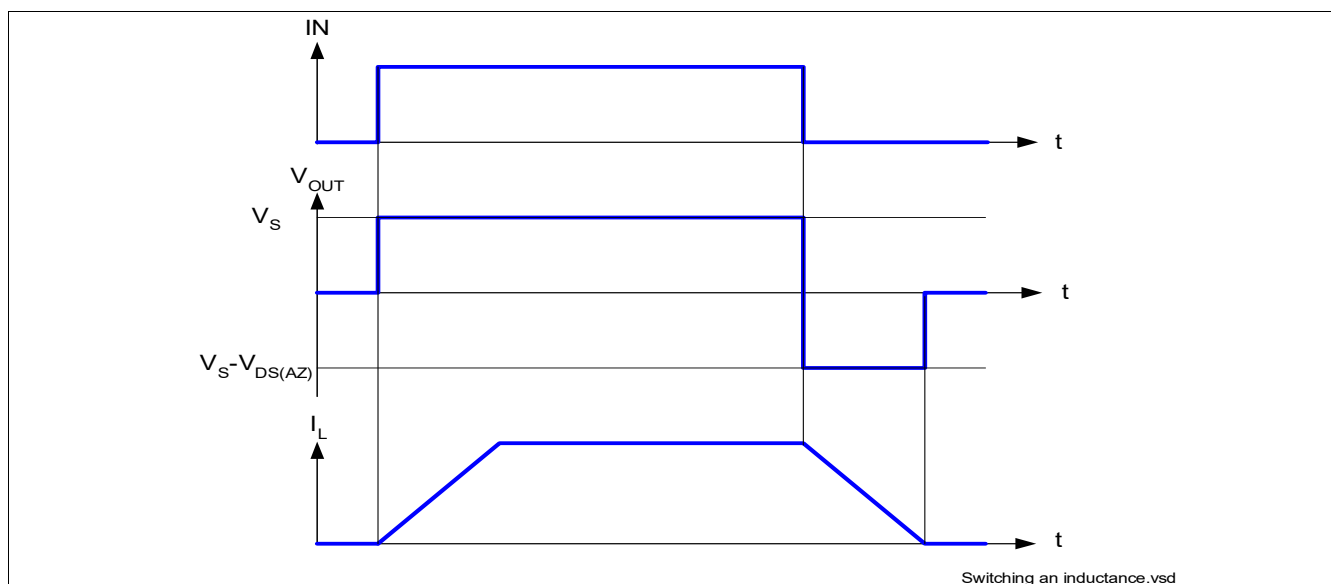


Figure 11 Switching an Inductive Load Timing

**Power Stage**

### 5.3.2 Maximum Load Inductance

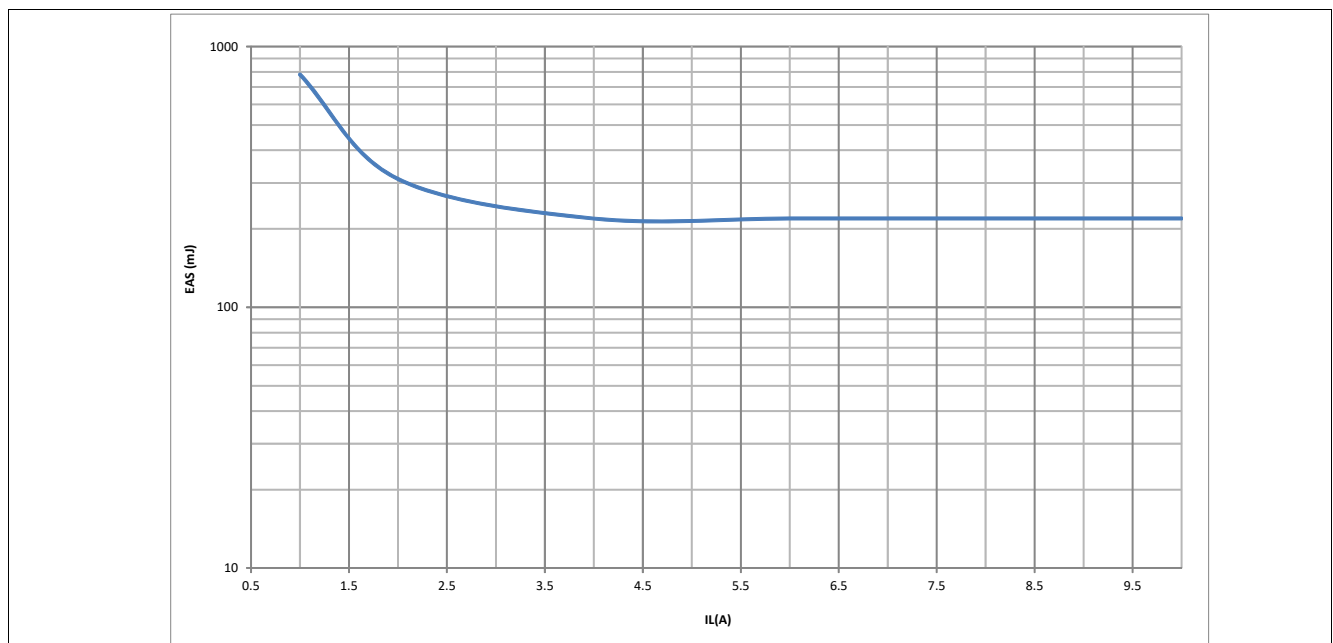
During demagnetization of inductive loads, energy has to be dissipated in the BTT6010-1ERB. This energy can be calculated with the following equation:

$$E = V_{DS(AZ)} \cdot \frac{L}{R_L} \cdot \left[ \frac{V_S - V_{DS(AZ)}}{R_L} \cdot \ln \left( 1 - \frac{R_L \cdot I_L}{V_S - V_{DS(AZ)}} \right) + I_L \right] \quad (5.1)$$

Following equation simplifies under the assumption of  $R_L = 0 \Omega$ .

$$E = \frac{1}{2} \cdot L \cdot I^2 \cdot \left( 1 - \frac{V_S}{V_S - V_{DS(AZ)}} \right) \quad (5.2)$$

The energy, which is converted into heat, is limited by the thermal design of the component. See **Figure 12** for the maximum allowed energy dissipation as a function of the load current.

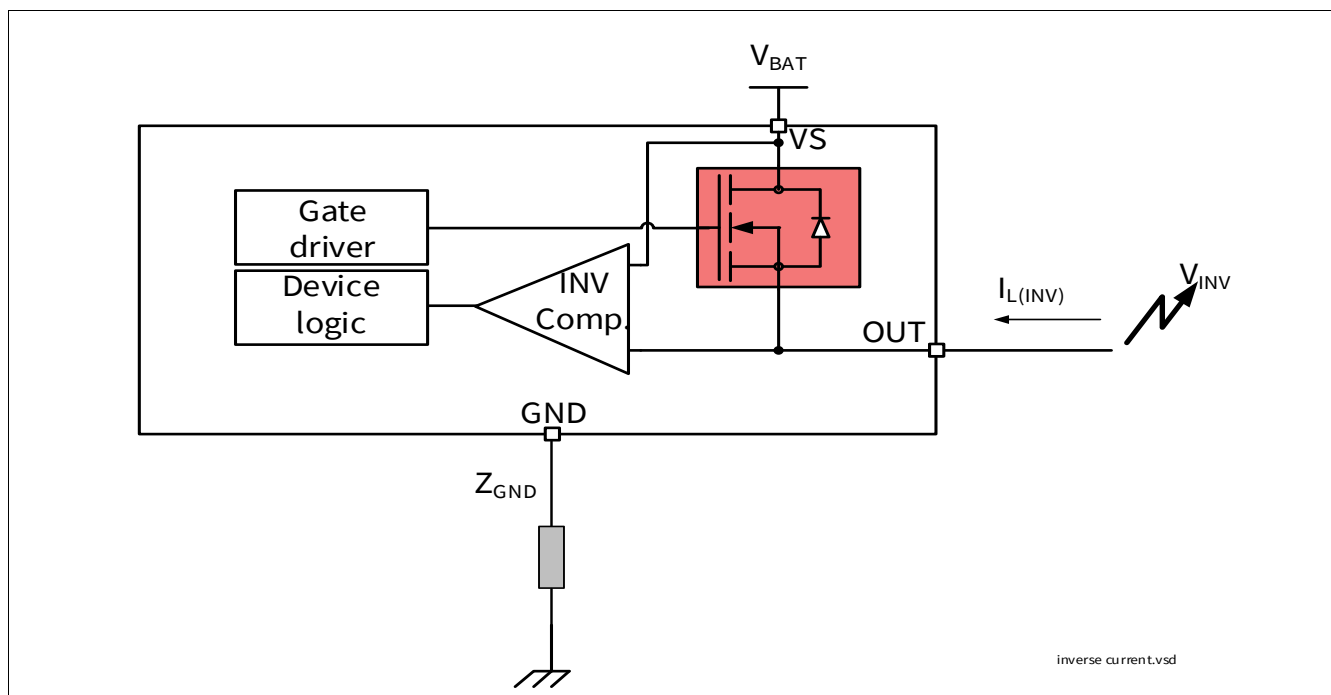


**Figure 12** Maximum Energy Dissipation Single Pulse,  $T_{J\_START} = 150^{\circ}\text{C}$ ;  $V_S = 28 \text{ V}$

## Power Stage

### 5.4 Inverse Current Capability

In case of inverse current, meaning a voltage  $V_{INV}$  at the OUTput higher than the supply voltage  $V_S$ , a current  $I_{INV}$  will flow from output to  $V_S$  pin via the body diode of the power transistor (please refer to [Figure 13](#)). The output stage follows the state of the IN pin, except if the IN pin goes from OFF to ON during inverse. In that particular case, the output stage is kept OFF until the inverse current disappears. Nevertheless, the current  $I_{INV}$  should not be higher than  $I_{L(INV)}$ . If the channel is OFF, the diagnostic will detect an open load at OFF. If the affected channel is ON, the diagnostic will detect open load at ON (the overtemperature signal is inhibited). At the appearance of  $V_{INV}$ , a parasitic diagnostic can be observed. After, the diagnosis is valid and reflects the output state. At  $V_{INV}$  vanishing, the diagnosis is valid and reflects the output state. During inverse current, no protection functions are available.



**Figure 13 Inverse Current Circuitry**

**Power Stage**

**5.5 Electrical Characteristics Power Stage**

**Table 6 Electrical Characteristics: Power Stage**

$V_S = 8 \text{ V to } 36 \text{ V}$ ,  $T_J = -40^\circ\text{C to } +150^\circ\text{C}$  (unless otherwise specified).

Typical values are given at  $V_S = 28 \text{ V}$ ,  $T_J = 25^\circ\text{C}$

| Parameter                                                          | Symbol           | Values |      |      | Unit | Note or Test Condition                                                                                                 | Number   |
|--------------------------------------------------------------------|------------------|--------|------|------|------|------------------------------------------------------------------------------------------------------------------------|----------|
|                                                                    |                  | Min.   | Typ. | Max. |      |                                                                                                                        |          |
| ON-state resistance per channel                                    | $R_{DS(ON)_150}$ | 15     | 20   | 22   | mΩ   | $I_L = I_{L4} = 10 \text{ A}$<br>$V_{IN} = 4.5 \text{ V}$<br>$T_J = 150^\circ\text{C}$<br>See <a href="#">Figure 8</a> | P_5.5.1  |
| ON-state resistance per channel                                    | $R_{DS(ON)_25}$  | –      | 10   | –    | mΩ   | <sup>1)</sup> $T_J = 25^\circ\text{C}$                                                                                 | P_5.5.21 |
| Nominal load current                                               | $I_{L(NOM)}$     | –      | 9    | –    | A    | <sup>1)</sup> $T_A = 85^\circ\text{C}$<br>$T_J < 150^\circ\text{C}$                                                    | P_5.5.2  |
| Output voltage drop limitation at small load currents              | $V_{DS(NL)}$     | –      | 10   | 22   | mV   | $I_L = I_{L0} = 50 \text{ mA}$<br>See <a href="#">Chapter 9</a>                                                        | P_5.5.4  |
| Drain to source clamping voltage<br>$V_{DS(AZ)} = [V_S - V_{OUT}]$ | $V_{DS(AZ)}$     | 66     | 70   | 75   | V    | $I_{DS} = 20 \text{ mA}$<br>See <a href="#">Figure 11</a><br>See <a href="#">Chapter 9</a>                             | P_5.5.5  |
| Output leakage current<br>$T_J \leq 85^\circ\text{C}$              | $I_{L(OFF)}$     | –      | 0.05 | 0.5  | μA   | <sup>2)</sup> $V_{IN}$ floating<br>$V_{OUT} = 0 \text{ V}$<br>$T_J \leq 85^\circ\text{C}$                              | P_5.5.6  |
| Output leakage current<br>$T_J = 150^\circ\text{C}$                | $I_{L(OFF)_150}$ | –      | 8    | 15   | μA   | $V_{IN}$ floating<br>$V_{OUT} = 0 \text{ V}$<br>$T_J = 150^\circ\text{C}$                                              | P_5.5.8  |
| Slew rate<br>30% to 70% $V_S$                                      | $dV/dt_{ON}$     | 0.3    | 0.65 | 1.4  | V/μs | $R_L = 4 \Omega$<br>$V_S = 28 \text{ V}$                                                                               | P_5.5.11 |
| Slew rate<br>70% to 30% $V_S$                                      | $-dV/dt_{OFF}$   | 0.3    | 0.65 | 1.4  | V/μs | See <a href="#">Figure 9</a><br>See <a href="#">Chapter 9</a>                                                          | P_5.5.12 |
| Slew rate matching<br>$dV/dt_{ON} - dV/dt_{OFF}$                   | $\Delta dV/dt$   | -0.15  | 0    | 0.15 | V/μs |                                                                                                                        | P_5.5.13 |
| Turn-ON time to $V_{OUT} = 90\% V_S$                               | $t_{ON}$         | 20     | 70   | 150  | μs   |                                                                                                                        | P_5.5.14 |
| Turn-OFF time to $V_{OUT} = 10\% V_S$                              | $t_{OFF}$        | 20     | 70   | 150  | μs   |                                                                                                                        | P_5.5.15 |
| Turn-ON / OFF matching<br>$t_{OFF} - t_{ON}$                       | $\Delta t_{SW}$  | -50    | 0    | 50   | μs   |                                                                                                                        | P_5.5.16 |
| Turn-ON time to $V_{OUT} = 10\% V_S$                               | $t_{ON\_delay}$  | –      | 35   | 70   | μs   |                                                                                                                        | P_5.5.17 |
| Turn-OFF time to $V_{OUT} = 90\% V_S$                              | $t_{OFF\_delay}$ | –      | 35   | 70   | μs   |                                                                                                                        | P_5.5.18 |

**Power Stage**

**Table 6 Electrical Characteristics: Power Stage** (cont'd)

$V_S = 8\text{ V to }36\text{ V}$ ,  $T_J = -40^\circ\text{C to }+150^\circ\text{C}$  (unless otherwise specified).

Typical values are given at  $V_S = 28\text{ V}$ ,  $T_J = 25^\circ\text{C}$

| Parameter         | Symbol           | Values |      |      | Unit | Note or Test Condition                                                                                                 | Number   |
|-------------------|------------------|--------|------|------|------|------------------------------------------------------------------------------------------------------------------------|----------|
|                   |                  | Min.   | Typ. | Max. |      |                                                                                                                        |          |
| Switch ON energy  | $E_{\text{ON}}$  | –      | 2.1  | –    | mJ   | <sup>1)</sup> $R_L = 4\ \Omega$<br>$V_{\text{OUT}} = 90\% V_S$<br>$V_S = 36\text{ V}$<br>See <a href="#">Chapter 9</a> | P_5.5.19 |
| Switch OFF energy | $E_{\text{OFF}}$ | –      | 2.3  | –    | mJ   | <sup>1)</sup> $R_L = 4\ \Omega$<br>$V_{\text{OUT}} = 10\% V_S$<br>$V_S = 36\text{ V}$<br>See <a href="#">Chapter 9</a> | P_5.5.20 |

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

2) Test at  $T_J = -40^\circ\text{C}$  only

## 6 Protection Functions

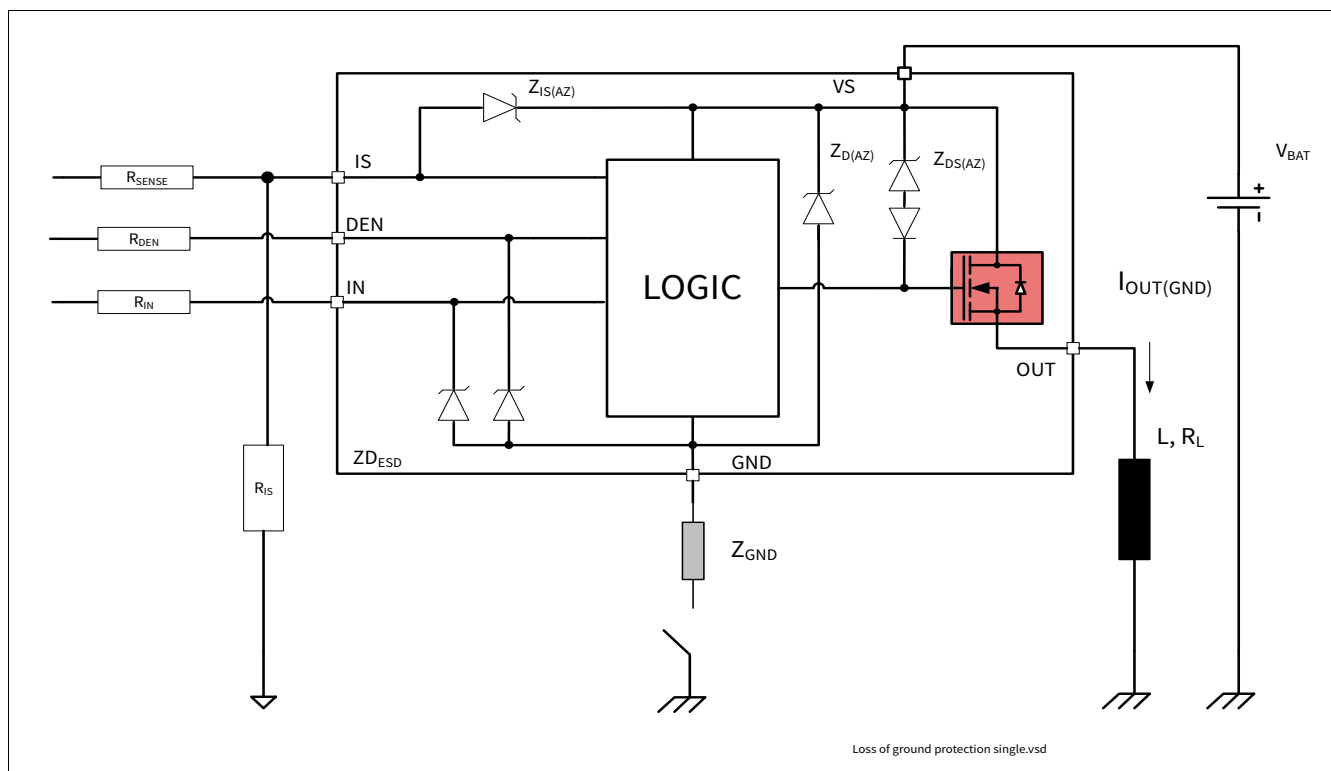
The device provides integrated protection functions. These functions are designed to prevent the destruction of the IC from fault conditions described in the data sheet. Fault conditions are considered as “outside” normal operating range. Protection functions are designed for neither continuous nor repetitive operation.

### 6.1 Loss of Ground Protection

In case of loss of the module ground and 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 on IN pin.

In case of loss of device ground, it's recommended to use input resistors between the microcontroller and the BTT6010-1ERB to ensure switching OFF of the channel.

In case of loss of module or device ground, a current ( $I_{OUT(GND)}$ ) can flow out of the DMOS. **Figure 14** sketches the situation.

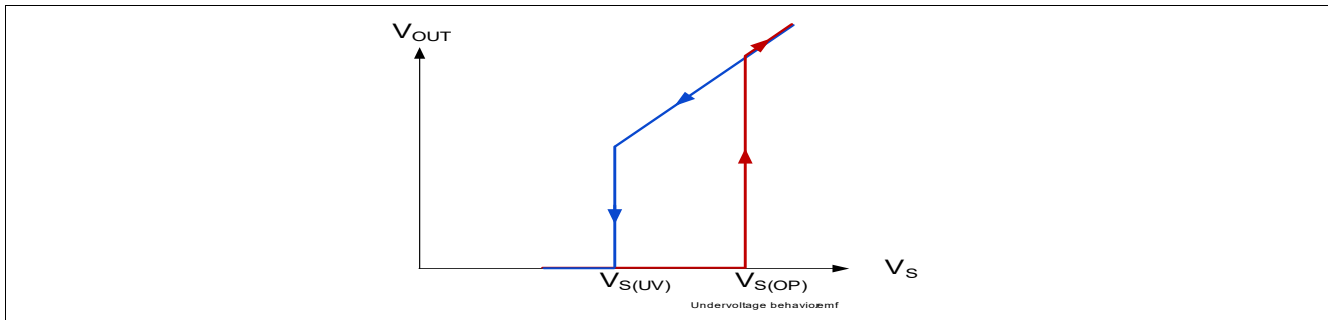


**Figure 14 Loss of Ground Protection with External Components**

### 6.2 Undervoltage Protection

Between  $V_{S(UV)}$  and  $V_{S(OP)}$ , the undervoltage mechanism is triggered.  $V_{S(OP)}$  represents the minimum voltage where the switching ON and OFF can take place.  $V_{S(UV)}$  represents the minimum voltage the switch can hold ON. If the supply voltage is below the undervoltage mechanism  $V_{S(UV)}$ , the device is OFF (turns OFF). As soon as the supply voltage is above the undervoltage mechanism  $V_{S(OP)}$ , then the device can be switched ON. When the switch is ON, protection functions are operational. Nevertheless, the diagnosis is not guaranteed until  $V_S$  is in the  $V_{NOM}$  range. **Figure 15** illustrates the undervoltage mechanism.

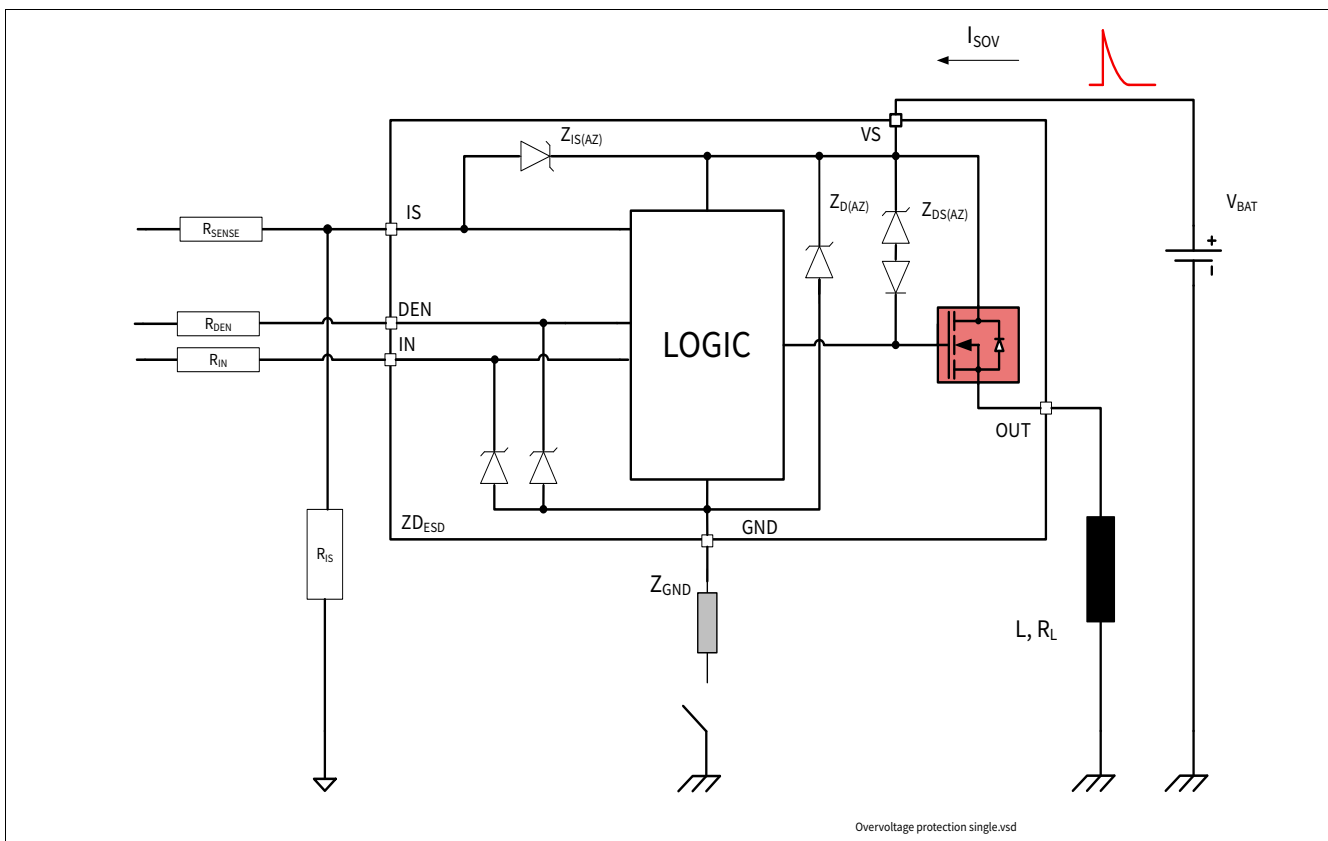
## Protection Functions



### Figure 15 Undervoltage Behavior

### 6.3 Overvoltage Protection

There is an integrated clamp mechanism for overvoltage protection ( $Z_{D(AZ)}$ ). To guarantee this mechanism operates properly in the application, the current in the Zener diode has to be limited by a ground resistor. **Figure 16** shows a typical application to withstand overvoltage issues. In case of supply voltage higher than  $V_{S(AZ)}$ , the power transistor switches ON and in addition the voltage across the logic section is clamped. As a result, the internal ground potential rises to  $V_S - V_{S(AZ)}$ . Due to the ESD Zener diodes, the potential at pin IN and DEN rises almost to that potential, depending on the impedance of the connected circuitry. In the case the device was ON, prior to overvoltage, the BTT6010-1ERB remains ON. In the case the BTT6010-1ERB was OFF, prior to overvoltage, the power transistor can be activated. In the case the supply voltage is in above  $V_{BAT(SC)}$  and below  $V_{DS(AZ)}$ , the output transistor is still operational and follows the input. If the channel is in the ON state, parameters are no longer guaranteed and lifetime is reduced compared to the nominal supply voltage range. This especially impacts the short circuit robustness, as well as the maximum energy  $E_{AS}$  capability.



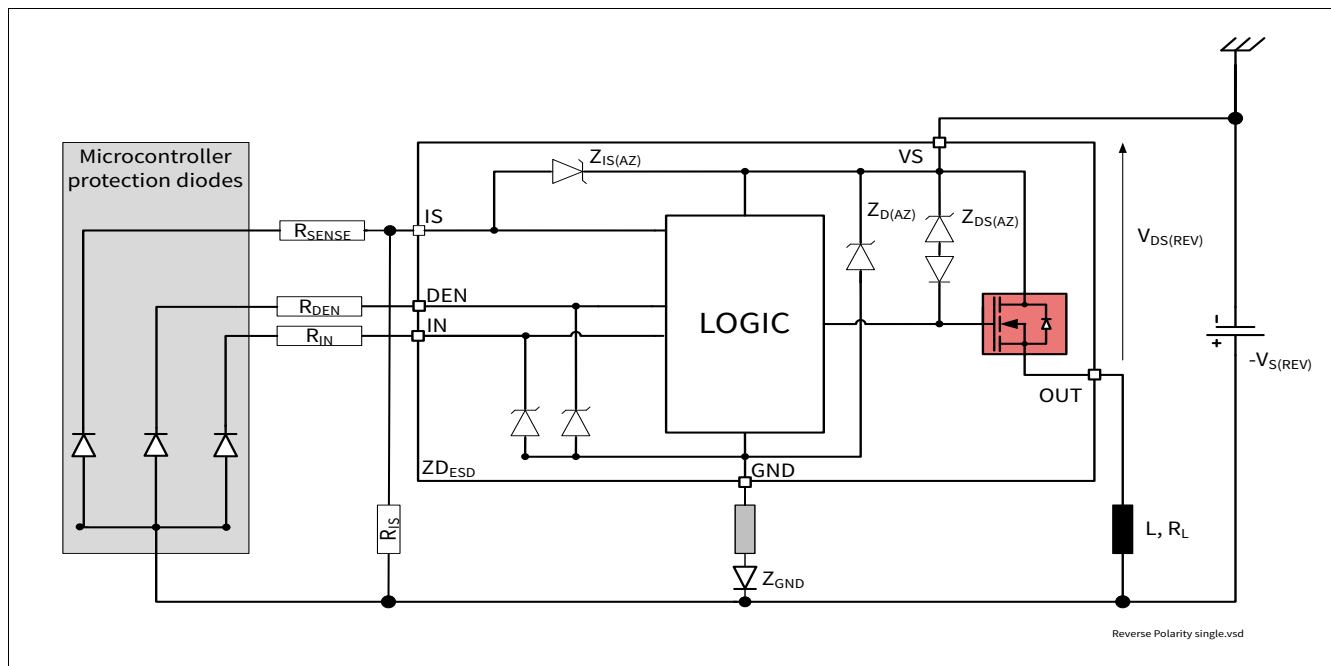
### Figure 16 Overvoltage Protection with External Components

## Protection Functions

## 6.4 Reverse Polarity Protection

In case of reverse polarity, the intrinsic body diode of the power DMOS causes power dissipation. The current in this intrinsic body diode is limited by the load itself. Additionally, the current into the ground path and the logic pins has to be limited to the maximum current described in [Chapter 4.1](#) with an external resistor. **Figure 17** shows a typical application.  $R_{\text{GND}}$  resistor is used to limit the current in the Zener protection of the device. Resistors  $R_{\text{DEN}}$  and  $R_{\text{IN}}$  are used to limit the current in the logic of the device and in the ESD protection stage.  $R_{\text{SENSE}}$  is used to limit the current in the sense transistor which behaves as a diode. The recommended value for  $R_{\text{DEN}} = R_{\text{IN}} = R_{\text{SENSE}} = 10 \text{ k}\Omega$ .

During reverse polarity, no protection functions are available.



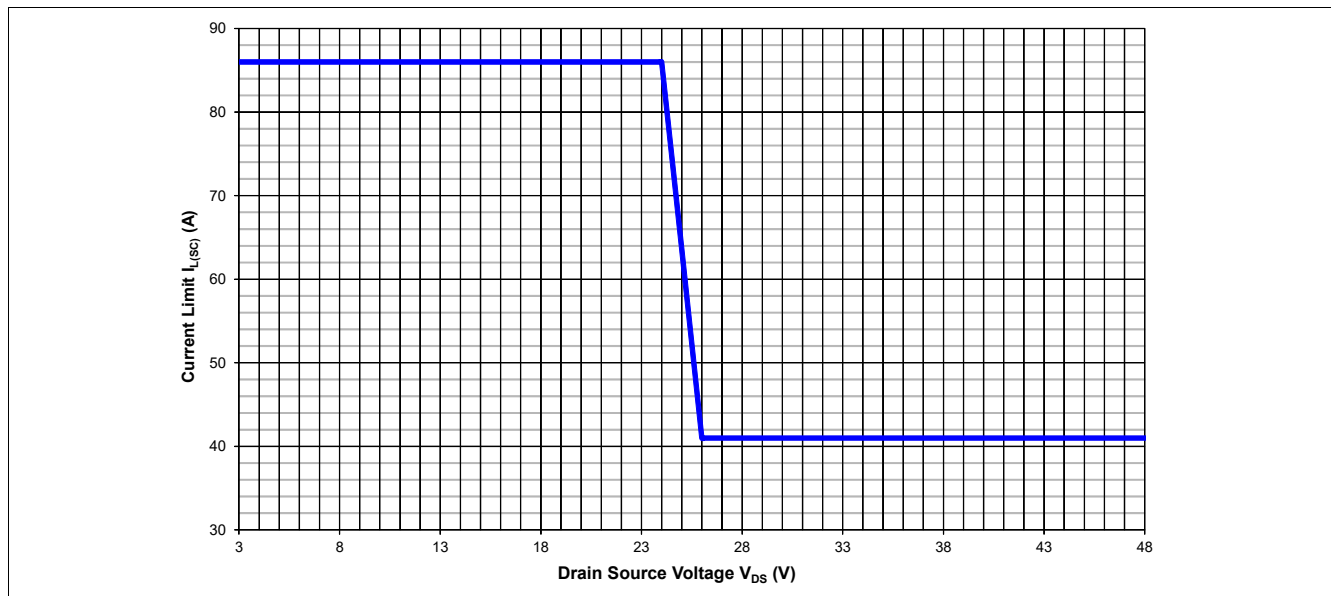
### Figure 17 Reverse Polarity Protection with External Components

## 6.5 Overload Protection

In case of overload, such as high inrush of cold lamp filament, or short circuit to ground, the BTT6010-1ERB offers several protection mechanisms.

### 6.5.1 Current Limitation

At first step, the instantaneous power in the switch is maintained at a safe value by limiting the current to the maximum current allowed in the switch  $I_{L(SC)}$ . During this time, the DMOS temperature is increasing, which affects the current flowing in the DMOS. The current limitation value is  $V_{DS}$  dependent. **Figure 18** shows the behavior of the current limitation as a function of the drain to source voltage.



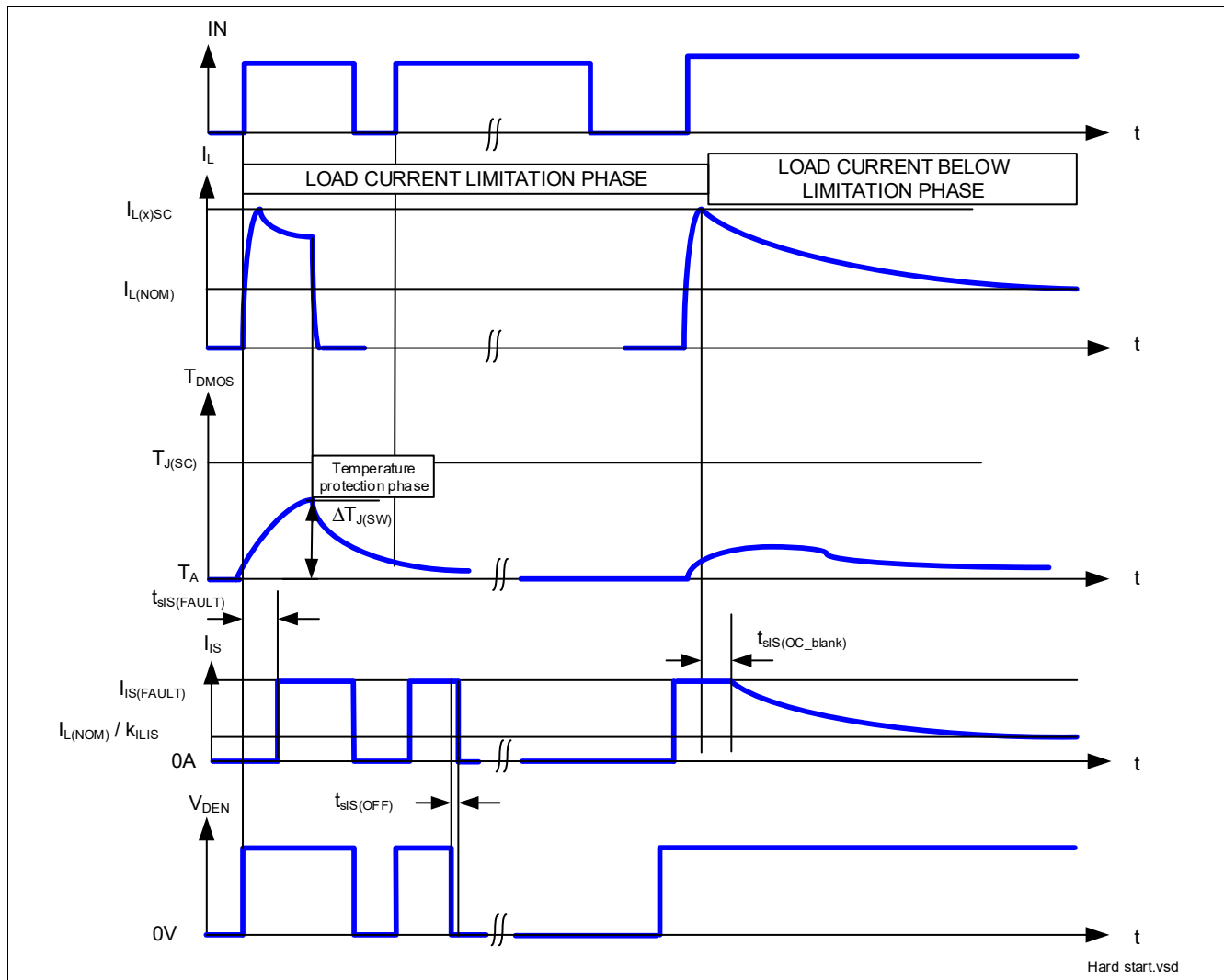
**Figure 18** Current Limitation (typical behavior)

## Protection Functions

### 6.5.2 Temperature Limitation in the Power DMOS

The channel incorporates both an absolute ( $T_{J(SC)}$ ) and a dynamic ( $T_{J(SW)}$ ) temperature sensor. Activation of either sensor will cause an overheated channel to switch OFF to prevent destruction. Any protective switch OFF latches the output until the temperature has reached an acceptable value. Figure 19 gives a sketch of the situation.

No retry strategy is implemented such that when the DMOS temperature has cooled down enough, the switch is switched ON again. Only the IN pin signal toggling can re-activate the power stage (latch behavior).



**Figure 19 Overload Protection**

*Note: For better understanding, the time scale is not linear. The real timing of this drawing is application dependant and cannot be described.*

**Protection Functions**

## 6.6 Electrical Characteristics for the Protection Functions

**Table 7 Electrical Characteristics: Protection**

$V_S = 8\text{ V to }36\text{ V}$ ,  $T_J = -40^\circ\text{C to }+150^\circ\text{C}$  (unless otherwise specified).  
 Typical values are given at  $V_S = 28\text{ V}$ ,  $T_J = 25^\circ\text{C}$

| Parameter                                          | Symbol                    | Values |                   |                   | Unit | Note or Test Condition                                                                        | Number   |
|----------------------------------------------------|---------------------------|--------|-------------------|-------------------|------|-----------------------------------------------------------------------------------------------|----------|
|                                                    |                           | Min.   | Typ.              | Max.              |      |                                                                                               |          |
| Loss of Ground                                     |                           |        |                   |                   |      |                                                                                               |          |
| Output leakage current while GND disconnected      | $I_{\text{OUT(GND)}}$     | –      | 0.1               | –                 | mA   | <sup>1) 2)</sup> $V_{\text{S}} = 48 \text{ V}$<br>See <b>Figure 14</b>                        | P_6.6.1  |
| Reverse Polarity                                   |                           |        |                   |                   |      |                                                                                               |          |
| Drain source diode voltage during reverse polarity | $V_{\text{DS(REV)}}$      | 420    | 650               | 700               | mV   | $I_{\text{L}} = -4 \text{ A}$<br>$T_{\text{J}} = 150^{\circ}\text{C}$<br>See <b>Figure 17</b> | P_6.6.2  |
| Overvoltage                                        |                           |        |                   |                   |      |                                                                                               |          |
| Overvoltage protection                             | $V_{\text{S(AZ)}}$        | 66     | 70                | 75                | V    | $I_{\text{SOV}} = 5 \text{ mA}$<br>See <b>Figure 16</b>                                       | P_6.6.3  |
| Overload Condition                                 |                           |        |                   |                   |      |                                                                                               |          |
| Load current limitation                            | $I_{\text{L5(SC)}}$       | 68     | 86                | 104               | A    | <sup>3)</sup> $V_{\text{DS}} = 7 \text{ V}$<br>See <b>Chapter 9</b>                           | P_6.6.4  |
| Load current limitation                            | $I_{\text{L28(SC)}}$      | –      | 41                | –                 | A    | <sup>2)</sup> $V_{\text{DS}} = 42 \text{ V}$<br>See <b>Figure 18</b>                          | P_6.6.7  |
| Dynamic temperature increase while switching       | $\Delta T_{\text{J(SW)}}$ | –      | 80                | –                 | K    | <sup>4)</sup> See <b>Figure 19</b>                                                            | P_6.6.8  |
| Thermal shutdown temperature                       | $T_{\text{J(SC)}}$        | 150    | 170 <sup>4)</sup> | 200 <sup>4)</sup> | °C   | <sup>5)</sup> See <b>Figure 19</b>                                                            | P_6.6.10 |
| Thermal shutdown hysteresis                        | $\Delta T_{\text{J(SC)}}$ | –      | 30                | –                 | K    | <sup>5) 4)</sup> See <b>Figure 19</b>                                                         | P_6.6.11 |

1) All pins are disconnected except VS and OUT.

2) Not Subject to production test, specified by design

3) Test at  $T_J = -40^\circ\text{C}$  only

4) Functional test only

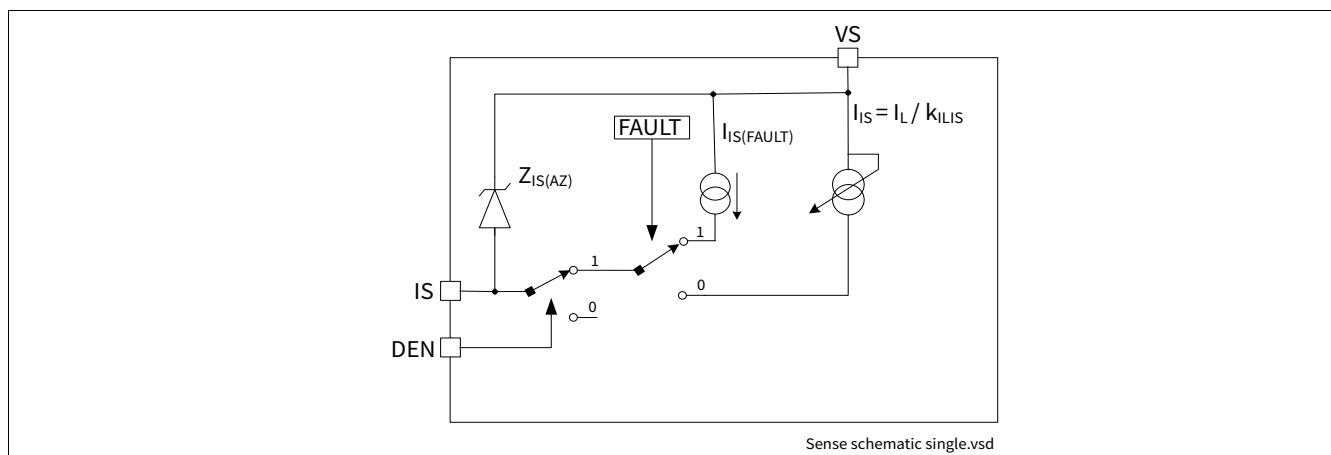
5) Test at  $T_J = +150^\circ\text{C}$  only

## 7 Diagnostic Functions

For diagnosis purpose, the BTT6010-1ERB provides a combination of digital and analog signals at pin IS. These signals are called SENSE. In case the diagnostic is disabled via DEN, pin IS becomes high impedance. In case DEN is activated, the sense current of the channel is enabled.

### 7.1 IS Pin

The BTT6010-1ERB provides a sense current called  $I_{IS}$  at pin IS. As long as no “hard” failure mode occurs (short circuit to GND / current limitation / overtemperature / excessive dynamic temperature increase or open load at OFF) a proportional signal to the load current (ratio  $k_{ILIS} = I_L / I_{IS}$ ) is provided. The complete IS pin and diagnostic mechanism is described on [Figure 20](#). The accuracy of the sense current depends on temperature and load current. Due to the ESD protection, in connection to  $V_S$ , it is not recommended to share the IS pin with other devices if these devices are using another battery feed. The consequence is that the unsupplied device would be fed via the IS pin of the supplied device.



**Figure 20 Diagnostic Block Diagram**

## Diagnostic Functions

### 7.2 SENSE Signal in Different Operating Modes

**Table 8** gives a quick reference for the state of the IS pin during device operation.

**Table 8 Sense Signal, Function of Operation Mode**

| Operation Mode                    | Input level Channel X | DEN | Output Level                            | Diagnostic Output                      |
|-----------------------------------|-----------------------|-----|-----------------------------------------|----------------------------------------|
| Normal operation                  | OFF                   | H   | Z                                       | Z                                      |
| Short circuit to GND              |                       |     | ~ GND                                   | Z                                      |
| Overtemperature                   |                       |     | Z                                       | Z                                      |
| Short circuit to $V_S$            |                       |     | $V_S$                                   | $I_{IS(FAULT)}$                        |
| Open Load                         |                       |     | $< V_{OL(OFF)}$<br>$> V_{OL(OFF)}^{1)}$ | Z<br>$I_{IS(FAULT)}$                   |
| Inverse current                   |                       |     | $\sim V_{INV}$                          | $I_{IS(FAULT)}$                        |
| Normal operation                  | ON                    |     | $\sim V_S$                              | $I_{IS} = I_L / k_{ILIS}$              |
| Current limitation                |                       |     | $< V_S$                                 | $I_{IS(FAULT)}$                        |
| Short circuit to GND              |                       |     | ~ GND                                   | $I_{IS(FAULT)}$                        |
| Overtemperature $T_{J(SW)}$ event |                       |     | Z                                       | $I_{IS(FAULT)}$                        |
| Short circuit to $V_S$            |                       |     | $V_S$                                   | $I_{IS} < I_L / k_{ILIS}$              |
| Open Load                         |                       |     | $\sim V_S^{2)}$                         | $I_{IS} < I_{IS(OL)}$                  |
| Inverse current                   |                       |     | $\sim V_{INV}$                          | $I_{IS} < I_{IS(OL)}^{3)}$             |
| Underload                         |                       |     | $\sim V_S^{4)}$                         | $I_{IS(OL)} < I_{IS} < I_L / k_{ILIS}$ |
| Don't care                        | Don't care            | L   | Don't care                              | Z                                      |

1) With additional pull-up resistor.

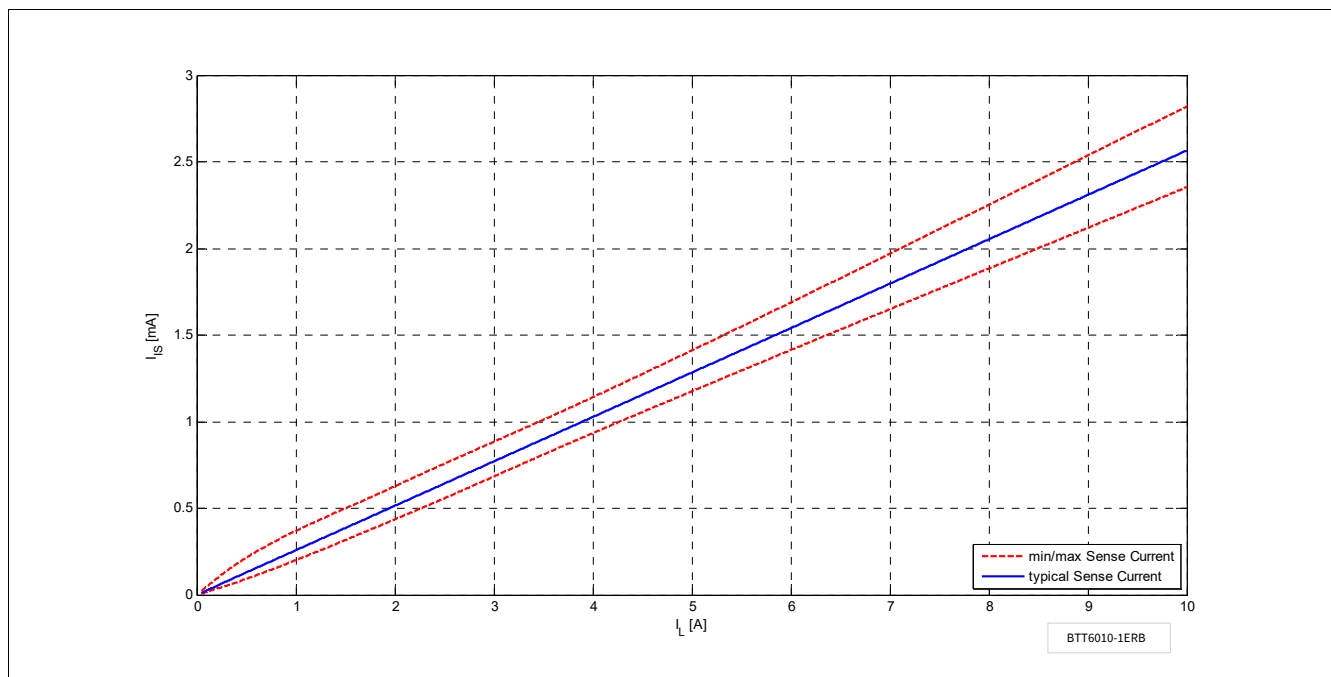
2) The output current has to be smaller than  $I_{L(OL)}$ .

3) After maximum  $t_{INV}$ .

4) The output current has to be higher than  $I_{L(OL)}$ .

### 7.3 SENSE Signal in the Nominal Current Range

**Figure 21** and **Figure 22** show the current sense as a function of the load current in the power DMOS. Usually, a pull-down resistor  $R_{IS}$  is connected to the current sense IS pin. This resistor has to be higher than 560  $\Omega$  to limit the power losses in the sense circuitry. A typical value is 1.2 k $\Omega$ . The blue curve represents the ideal sense current, assuming an ideal  $k_{ILIS}$  factor value. The red curves show the accuracy the device provide across full temperature range, at a defined current.



**Figure 21** Current Sense for Nominal Load

#### 7.3.1 SENSE Signal Variation as a Function of Temperature and Load Current

In some applications a better accuracy is required around half the nominal current  $I_{L(NOM)}$ . To achieve this accuracy requirement, a calibration on the application is possible. To avoid multiple calibration points at different load and temperature conditions, the BTT6010-1ERB allows limited derating of the  $k_{ILIS}$  value, at a given point ( $I_{L3}$ ;  $T_J = +25^\circ\text{C}$ ). This derating is described by the parameter  $\Delta k_{ILIS}$ . **Figure 22** shows the behavior of the sense current, assuming one calibration point at nominal load at  $+25^\circ\text{C}$ .

The blue line indicates the ideal  $k_{ILIS}$  ratio.

The green lines indicate the derating on the parameter across temperature and voltage, assuming one calibration point at nominal temperature and nominal battery voltage.

The red lines indicate the  $k_{ILIS}$  accuracy without calibration.

## Diagnostic Functions

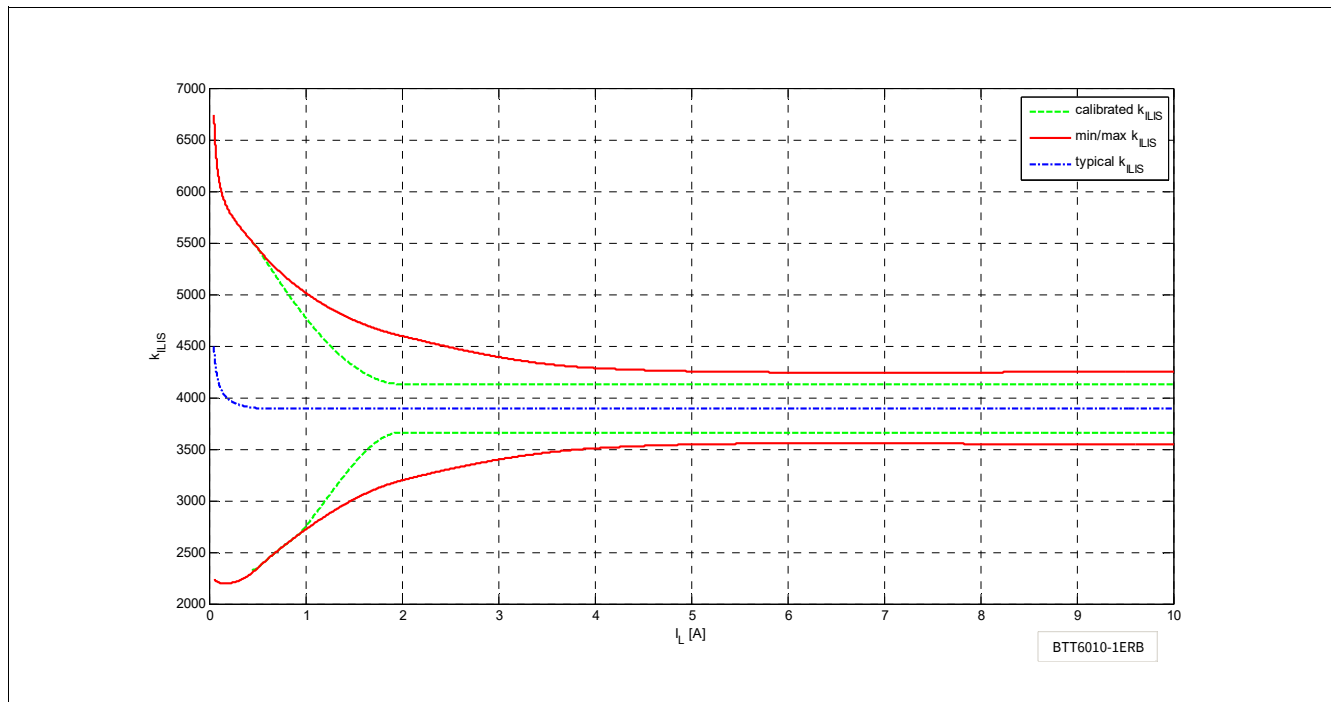


Figure 22 Improved Current Sense Accuracy with One Calibration

### 7.3.2 SENSE Signal Timing

Figure 23 shows the timing during settling and disabling of the sense.

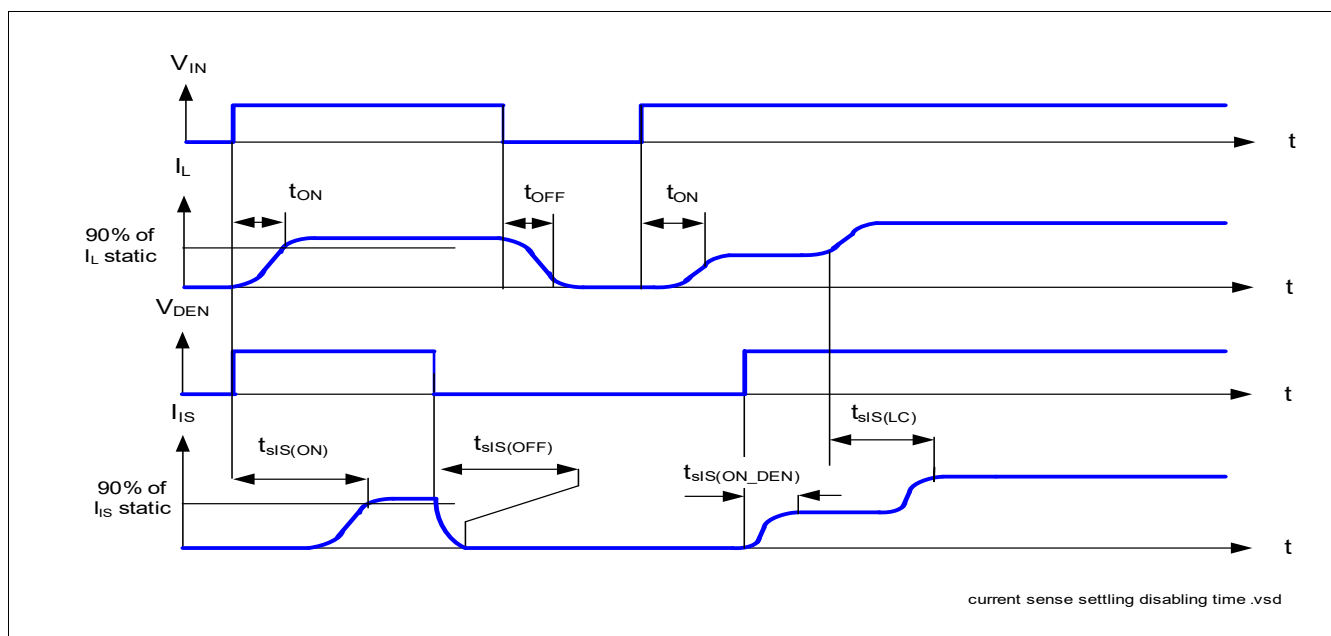
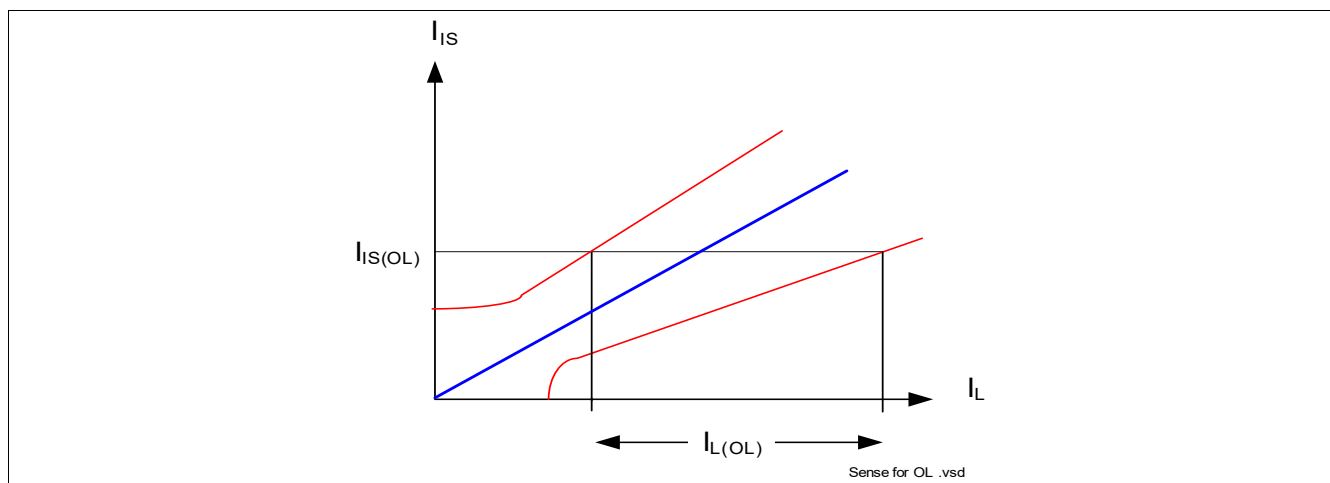


Figure 23 Current Sense Settling / Disabling Timing

### 7.3.3 SENSE Signal in Open Load

#### 7.3.3.1 Open Load in ON Diagnostic

If the channel is ON, a leakage current can still flow through an open load, for example due to humidity. The parameter  $I_{L(OL)}$  gives the threshold of recognition for this leakage current. If the current  $I_L$  flowing out the power DMOS is below this value, the device recognizes a failure, if the DEN is selected. In that case, the SENSE current is below  $I_{IS(OL)}$ . Otherwise, the minimum SENSE current is given above parameter  $I_{IS(OL)}$ . **Figure 24** shows the SENSE current behavior in this area. The red curve shows a typical product curve. The blue curve shows the ideal current sense.



**Figure 24** Current Sense Ratio for Low Currents

#### 7.3.3.2 Open Load in OFF Diagnostic

For open load diagnosis in OFF-state, an external output pull-up resistor ( $R_{OL}$ ) is recommended. For the calculation of pull-up resistor value, the leakage currents and the open load threshold voltage  $V_{OL(OFF)}$  have to be taken into account. **Figure 25** gives a sketch of the situation.  $I_{leakage}$  defines the leakage current in the complete system, including  $I_{L(OFF)}$  (see **Chapter 5.5**) and external leakages, e.g. due to humidity, corrosion, etc.... in the application.

To reduce the stand-by current of the system, an open load resistor switch  $S_{OL}$  is recommended. If the channel is OFF, the output is no longer pulled down by the load and  $V_{OUT}$  voltage rises to nearly  $V_S$ . This is recognized by the device as an open load. The voltage threshold is given by  $V_{OL(OFF)}$ . In that case, the SENSE signal is switched to the  $I_{IS(FAULT)}$ .

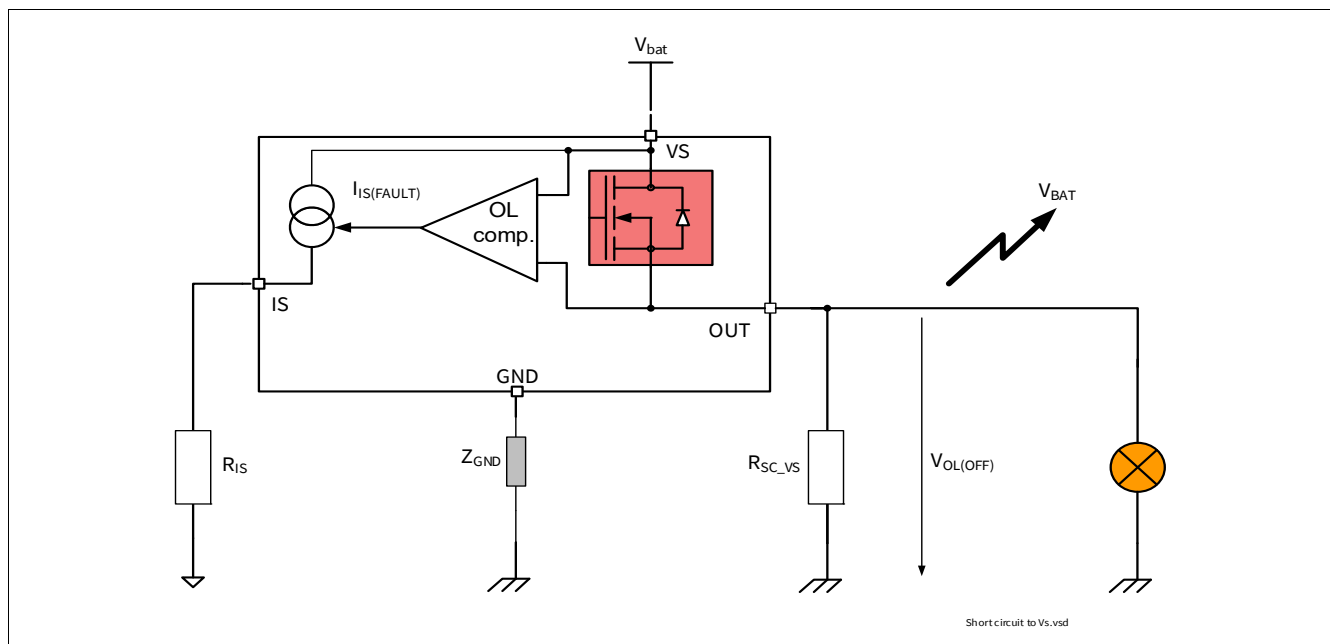
An additional  $R_{PD}$  resistor can be used to pull  $V_{OUT}$  to 0 V. Otherwise, the OUT pin is floating. This resistor can be used as well for short circuit to battery detection, see **Chapter 7.3.4**.



## Diagnostic Functions

### 7.3.4 SENSE Signal with OUT in Short Circuit to $V_S$

In case of a short circuit between the OUTput-pin and the  $V_S$  pin, all or portion (depending on the short circuit impedance) of the load current will flow through the short circuit. As a result, a lower current compared to the normal operation will flow through the DMOS of the BTT6010-1ERB, which can be recognized at the current sense signal. The open load at OFF detection circuitry can also be used to distinguish a short circuit to  $V_S$ . In that case, an external resistor to ground  $R_{SC\_VS}$  is required. **Figure 27** gives a sketch of the situation.



**Figure 27 Short Circuit to Battery Detection in OFF Electrical Equivalent Circuit**

### 7.3.5 SENSE Signal in Case of Overload

An overload condition is defined by a current flowing out of the DMOS reaching the current limitation and / or the absolute dynamic temperature swing  $T_{J(SW)}$  is reached, and / or the junction temperature reaches the thermal shutdown temperature  $T_{J(SC)}$ . Please refer to **Chapter 6.5** for details.

In that case, the SENSE signal given is by  $I_{IS(FAULT)}$  when the diagnostic is selected.

The device has a thermal latch behavior, such that when the overtemperature or the exceed dynamic temperature condition has disappeared, the DMOS is reactivated only when the IN is toggled LOW to HIGH. If the DEN pin is activated the SENSE follows the output stage. If no reset of the latch occurs, the device remains in the latching phase and  $I_{IS(FAULT)}$  at the IS pin, even though the DMOS is OFF.

### 7.3.6 SENSE Signal in Case of Inverse Current

In the case of inverse current, the sense signal will indicate open load in OFF state and indicate open load in ON state.

## Diagnostic Functions

### 7.4 Electrical Characteristics Diagnostic Function

**Table 9 Electrical Characteristics: Diagnostics**

$V_S = 8\text{ V}$  to  $36\text{ V}$ ,  $T_J = -40^\circ\text{C}$  to  $+150^\circ\text{C}$  (unless otherwise specified).  
Typical values are given at  $V_S = 28\text{ V}$ ,  $T_J = 25^\circ\text{C}$

| Parameter                                                                     | Symbol                    | Values |      |      | Unit          | Note or Test Condition                                                                                                                      | Number   |
|-------------------------------------------------------------------------------|---------------------------|--------|------|------|---------------|---------------------------------------------------------------------------------------------------------------------------------------------|----------|
|                                                                               |                           | Min.   | Typ. | Max. |               |                                                                                                                                             |          |
| Load Condition Threshold for Diagnostic                                       |                           |        |      |      |               |                                                                                                                                             |          |
| Open load detection threshold in OFF state                                    | $V_S - V_{OL(OFF)}$       | 4      | –    | 6    | V             | $V_{IN} = 0\text{ V}$<br>$V_{DEN} = 4.5\text{ V}$                                                                                           | P_7.5.1  |
| Open load detection threshold in ON state                                     | $I_{L(OL)}$               | 10     | –    | 50   | mA            | $V_{IN} = V_{DEN} = 4.5\text{ V}$<br>$I_{IS(OL)} = 6.5\text{ }\mu\text{A}$<br>See <b>Figure 24</b><br>See <b>Chapter 9</b>                  | P_7.5.2  |
| Sense Pin                                                                     |                           |        |      |      |               |                                                                                                                                             |          |
| IS pin leakage current when sense is disabled                                 | $I_{IS(DIS)}$             | –      | –    | 1    | $\mu\text{A}$ | $V_{IN} = 4.5\text{ V}$<br>$V_{DEN} = 0\text{ V}$<br>$I_L = I_{L4} = 10\text{ A}$                                                           | P_7.5.4  |
| Sense signal saturation voltage                                               | $V_S - V_{IS}$<br>(RANGE) | 1      | –    | 3.5  | V             | $V_{IN} = 0\text{ V}$<br>$V_{OUT} = V_S > 10\text{ V}$<br>$V_{DEN} = 4.5\text{ V}$<br>$I_{IS} = 6\text{ mA}$<br>See <b>Chapter 9</b>        | P_7.5.6  |
| Sense signal maximum current in fault condition                               | $I_{IS(FAULT)}$           | 6      | 20   | 40   | mA            | $V_{IS} = V_{IN} = 0\text{ V}$<br>$V_{OUT} = V_S > 10\text{ V}$<br>$V_{DEN} = 4.5\text{ V}$<br>See <b>Figure 20</b><br>See <b>Chapter 9</b> | P_7.5.7  |
| Sense pin maximum voltage                                                     | $V_{IS(AZ)}$              | 66     | 70   | 75   | V             | $I_{IS} = 5\text{ mA}$<br>See <b>Figure 20</b>                                                                                              | P_7.5.3  |
| Current Sense Ratio Signal in the Nominal Area, Stable Load Current Condition |                           |        |      |      |               |                                                                                                                                             |          |
| Current sense ratio<br>$I_{L0} = 50\text{ mA}$                                | $k_{ILIS0}$               | -50%   | 4500 | +50% |               | $V_{IN} = 4.5\text{ V}$<br>$V_{DEN} = 4.5\text{ V}$<br>See <b>Figure 21</b><br>$T_J = -40^{\circ}\text{C}; 150^{\circ}\text{C}$             | P_7.5.8  |
| Current sense ratio<br>$I_{L1} = 0.5\text{ A}$                                | $k_{ILIS1}$               | -40%   | 3900 | +40% |               |                                                                                                                                             | P_7.5.9  |
| Current sense ratio<br>$I_{L2} = 2\text{ A}$                                  | $k_{ILIS2}$               | -18%   | 3900 | +18% |               |                                                                                                                                             | P_7.5.10 |
| Current sense ratio<br>$I_{L3} = 4\text{ A}$                                  | $k_{ILIS3}$               | -10%   | 3900 | +10% |               |                                                                                                                                             | P_7.5.11 |
| Current sense ratio<br>$I_{L4} = 10\text{ A}$                                 | $k_{ILIS4}$               | -9%    | 3900 | +9%  |               |                                                                                                                                             | P_7.5.12 |
| $k_{ILIS}$ derating with current and temperature                              | $\Delta k_{ILIS}$         | -8     | 0    | +8   | %             | <sup>1)</sup> $k_{ILIS3}$ versus $k_{ILIS2}$<br>See <b>Figure 22</b>                                                                        | P_7.5.17 |

## Diagnostic Functions

**Table 9 Electrical Characteristics: Diagnostics (cont'd)**

$V_S = 8\text{ V to }36\text{ V}$ ,  $T_J = -40^\circ\text{C to }+150^\circ\text{C}$  (unless otherwise specified).

Typical values are given at  $V_S = 28\text{ V}$ ,  $T_J = 25^\circ\text{C}$

| Parameter                                                                                                  | Symbol                        | Values |      |      | Unit          | Note or Test Condition                                                                                                                                                                                 | Number   |
|------------------------------------------------------------------------------------------------------------|-------------------------------|--------|------|------|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
|                                                                                                            |                               | Min.   | Typ. | Max. |               |                                                                                                                                                                                                        |          |
| Diagnostic Timing in Normal Condition                                                                      |                               |        |      |      |               |                                                                                                                                                                                                        |          |
| Current sense settling time to $k_{ILIS}$ function stable after positive input slope on both INput and DEN | $t_{SIS(ON)}$                 | –      | –    | 150  | $\mu\text{s}$ | <sup>1)</sup> $V_{DEN} = V_{IN} = 0$ to $4.5\text{ V}$ ;<br>$V_S = 28\text{ V}$<br>$R_{IS} = 1.2\text{ k}\Omega$<br>$C_{SENSE} < 100\text{ pF}$<br>$I_L = I_{L3} = 4\text{ A}$<br>See <b>Figure 23</b> | P_7.5.18 |
| Current sense settling time with load current stable and transition of the DEN                             | $t_{SIS(ON\_DEN)}$            | –      | –    | 10   | $\mu\text{s}$ | $V_{IN} = 4.5\text{ V}$<br>$V_{DEN} = 0$ to $4.5\text{ V}$<br>$R_{IS} = 1.2\text{ k}\Omega$<br>$C_{SENSE} < 100\text{ pF}$<br>$I_L = I_{L3} = 4\text{ A}$<br>See <b>Figure 23</b>                      | P_7.5.19 |
| Current sense settling time to $I_{IS}$ stable after positive input slope on current load                  | $t_{SIS(LC)}$                 | –      | –    | 20   | $\mu\text{s}$ | $V_{IN} = 4.5\text{ V}$<br>$V_{DEN} = 4.5\text{ V}$<br>$R_{IS} = 1.2\text{ k}\Omega$<br>$C_{SENSE} < 100\text{ pF}$<br>$I_L = I_{L2} = 2\text{ A}$ to $I_{L3} = 4\text{ A}$ ;<br>See <b>Figure 23</b>  | P_7.5.20 |
| Diagnostic Timing in Open Load Condition                                                                   |                               |        |      |      |               |                                                                                                                                                                                                        |          |
| Current sense settling time to $I_{IS}$ stable for open load detection in OFF state                        | $t_{SIS(FAULT\_OL\_OFF)}$     | –      | –    | 100  | $\mu\text{s}$ | $V_{IN} = 0\text{ V}$<br>$V_{DEN} = 0$ to $4.5\text{ V}$<br>$R_{IS} = 1.2\text{ k}\Omega$<br>$C_{SENSE} < 100\text{ pF}$<br>$V_{OUT} = V_S = 28\text{ V}$<br>See <b>Figure 26</b>                      | P_7.5.22 |
| Current sense settling time for open load detection in ON-OFF transition                                   | $t_{SIS(FAULT\_OL\_ON\_OFF)}$ | –      | 200  | –    | $\mu\text{s}$ | <sup>1)</sup> $V_{IN} = 4.5$ to $0\text{ V}$<br>$V_{DEN} = 4.5\text{ V}$<br>$R_{IS} = 1.2\text{ k}\Omega$<br>$C_{SENSE} < 100\text{ pF}$<br>$V_{OUT} = V_S = 28\text{ V}$<br>See <b>Figure 26</b>      | P_7.5.23 |
| Diagnostic Timing in Overload Condition                                                                    |                               |        |      |      |               |                                                                                                                                                                                                        |          |
| Current sense settling time to $I_{IS}$ stable for overload detection                                      | $t_{SIS(FAULT)}$              | 0      | –    | 150  | $\mu\text{s}$ | <sup>1)</sup> $V_{IN} = V_{DEN} = 0$ to $4.5\text{ V}$<br>$R_{IS} = 1.2\text{ k}\Omega$<br>$C_{SENSE} < 100\text{ pF}$<br>$V_{DS} = 24\text{ V}$<br>See <b>Figure 19</b>                               | P_7.5.24 |

**Diagnostic Functions**

**Table 9 Electrical Characteristics: Diagnostics** (cont'd)

$V_S = 8\text{ V to }36\text{ V}$ ,  $T_J = -40^\circ\text{C to }+150^\circ\text{C}$  (unless otherwise specified).

Typical values are given at  $V_S = 28\text{ V}$ ,  $T_J = 25^\circ\text{C}$

| Parameter                                                                                             | Symbol                      | Values |      |      | Unit          | Note or Test Condition                                                                                                                                                                                                     | Number   |
|-------------------------------------------------------------------------------------------------------|-----------------------------|--------|------|------|---------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
|                                                                                                       |                             | Min.   | Typ. | Max. |               |                                                                                                                                                                                                                            |          |
| Current sense over current blanking time                                                              | $t_{\text{SIS(OC\_blank)}}$ | –      | 350  | –    | $\mu\text{s}$ | <sup>1)</sup> $V_{\text{IN}} = V_{\text{DEN}} = 4.5\text{ V}$<br>$R_{\text{IS}} = 1.2\text{ k}\Omega$<br>$C_{\text{SENSE}} < 100\text{ pF}$<br>$V_{\text{DS}} = 5\text{ V to }0\text{ V}$<br>See <a href="#">Figure 19</a> | P_7.5.32 |
| Diagnostic disable time<br>DEN transition to<br>$I_{\text{IS}} < 50\% I_{\text{L}} / k_{\text{ILIS}}$ | $t_{\text{SIS(OFF)}}$       | 0      | –    | 20   | $\mu\text{s}$ | $V_{\text{IN}} = 4.5\text{ V}$<br>$V_{\text{DEN}} = 4.5\text{ V to }0\text{ V}$<br>$R_{\text{IS}} = 1.2\text{ k}\Omega$<br>$C_{\text{SENSE}} < 100\text{ pF}$<br>$I_{\text{L}} = I_{\text{L3}} = 4\text{ A}$               | P_7.5.25 |

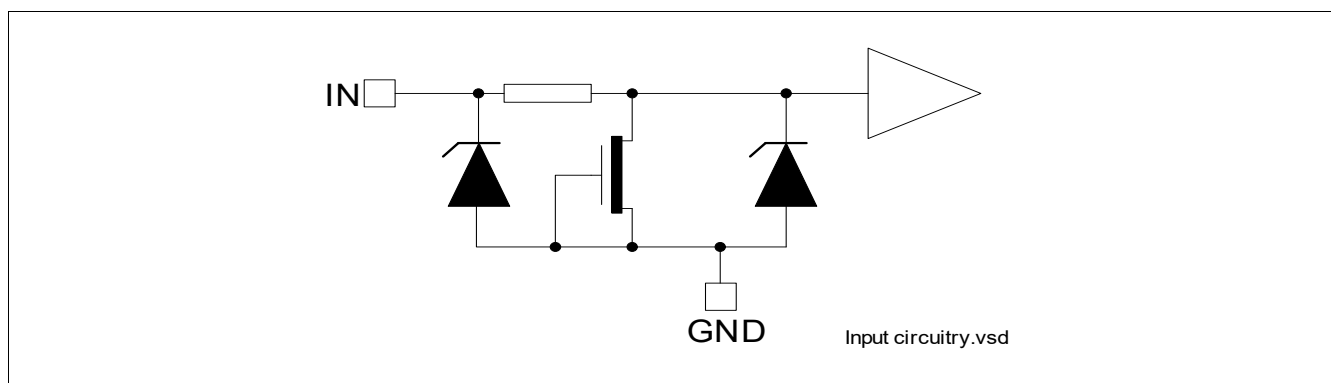
1) Not subject to production test, specified by design

## Input Pins

# 8 Input Pins

## 8.1 Input Circuitry

The input circuitry is compatible with 3.3 and 5 V microcontrollers. The concept of the input pin is to react to voltage thresholds. An implemented Schmitt trigger avoids any undefined state if the voltage on the input pin is slowly increasing or decreasing. The output is either OFF or ON but cannot be in a linear or undefined state. The input circuitry is compatible with PWM applications. **Figure 28** shows the electrical equivalent input circuitry. In case the pin is not needed, it must be left opened, or must be connected to device ground (and not module ground) via an input resistor.



**Figure 28** Input Pin Circuitry

## 8.2 DEN Pin

The DEN pin enables and disables the diagnostic functionality of the device. The pin has the same structure as the INput pin, please refer to **Figure 28**.

## 8.3 Input Pin Voltage

The IN and DEN use a comparator with hysteresis. The switching ON / OFF takes place in a defined region, set by the thresholds  $V_{IN(L)}$  Max. and  $V_{IN(H)}$  Min. The exact value where the ON and OFF take place are unknown and depends on the process, as well as the temperature. To avoid cross talk and parasitic turn ON and OFF, a hysteresis is implemented. This ensures a certain immunity to noise.

## Input Pins

### 8.4 Electrical Characteristics

**Table 10 Electrical Characteristics: Input Pins**

$V_S = 8\text{ V to }36\text{ V}$ ,  $T_J = -40^\circ\text{C to }+150^\circ\text{C}$  (unless otherwise specified).  
 Typical values are given at  $V_S = 28\text{ V}$ ,  $T_J = 25^\circ\text{C}$

| Parameter                      | Symbol               | Values |      |      | Unit | Note or Test Condition                                           | Number  |
|--------------------------------|----------------------|--------|------|------|------|------------------------------------------------------------------|---------|
|                                |                      | Min.   | Typ. | Max. |      |                                                                  |         |
| Input Pins Characteristics     |                      |        |      |      |      |                                                                  |         |
| Low level input voltage range  | $V_{\text{IN(L)}}$   | -0.3   | –    | 0.8  | V    | See <a href="#">Chapter 9</a>                                    | P_8.4.1 |
| High level input voltage range | $V_{\text{IN(H)}}$   | 2      | –    | 6    | V    | See <a href="#">Chapter 9</a>                                    | P_8.4.2 |
| Input voltage hysteresis       | $V_{\text{IN(HYS)}}$ | –      | 250  | –    | mV   | <sup>1)</sup> See <a href="#">Chapter 9</a>                      | P_8.4.3 |
| Low level input current        | $I_{\text{IN(L)}}$   | 1      | 10   | 25   | μA   | $V_{\text{IN}} = 0.8 \text{ V}$                                  | P_8.4.4 |
| High level input current       | $I_{\text{IN(H)}}$   | 2      | 10   | 25   | μA   | $V_{\text{IN}} = 5.5 \text{ V}$<br>See <a href="#">Chapter 9</a> | P_8.4.5 |

#### DEN Pin

|                                |                |      |     |     |               |                          |          |
|--------------------------------|----------------|------|-----|-----|---------------|--------------------------|----------|
| Low level input voltage range  | $V_{DEN(L)}$   | -0.3 | –   | 0.8 | V             | –                        | P_8.4.6  |
| High level input voltage range | $V_{DEN(H)}$   | 2    | –   | 6   | V             | –                        | P_8.4.7  |
| Input voltage hysteresis       | $V_{DEN(HYS)}$ | –    | 250 | –   | mV            | <sup>1)</sup>            | P_8.4.8  |
| Low level input current        | $I_{DEN(L)}$   | 1    | 10  | 25  | $\mu\text{A}$ | $V_{DEN} = 0.8\text{ V}$ | P_8.4.9  |
| High level input current       | $I_{DEN(H)}$   | 2    | 10  | 25  | $\mu\text{A}$ | $V_{DEN} = 5.5\text{ V}$ | P_8.4.10 |

<sup>1)</sup> Not subject to production test, specified by design

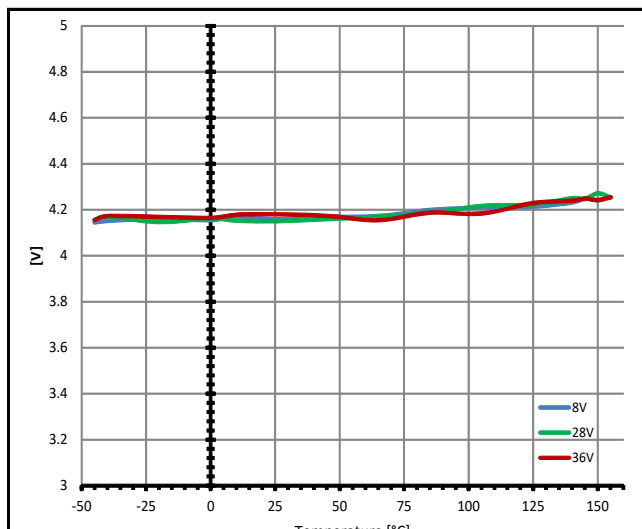
## Characterization Results

### 9 Characterization Results

The characterization has been performed on 3 lots, with 3 devices each. Characterization has been performed at 8 V, 28 V and 36 V over temperature range.

#### 9.1 General Product Characteristics

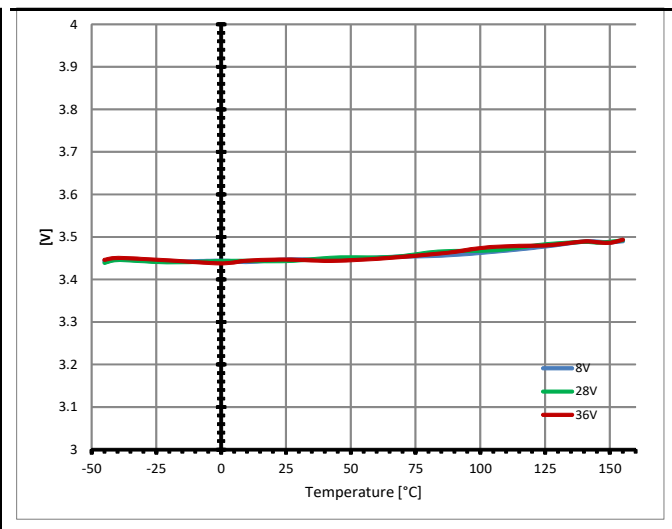
##### P\_4.2.3



**Minimum Functional Supply Voltage**

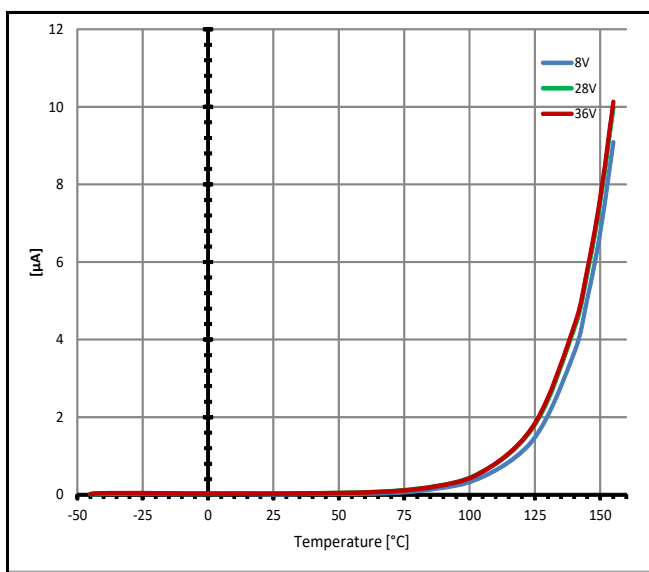
$$V_{S(OP\_MIN)} = f(T_J)$$

##### P\_4.2.4



**Undervoltage Threshold  $V_{S(UV)} = f(T_J)$**

##### P\_4.2.7



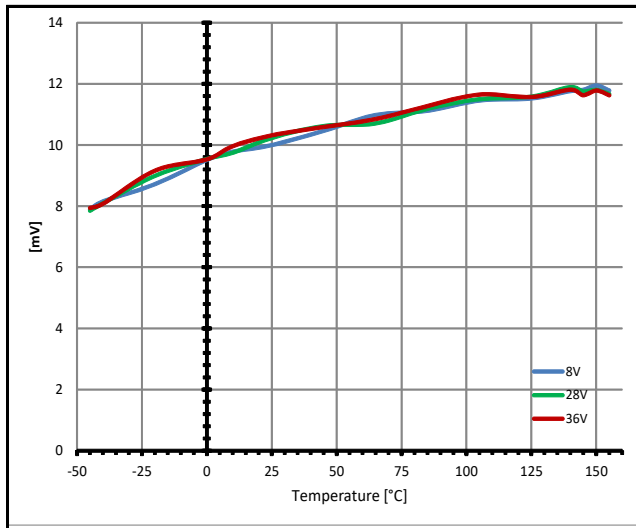
**Standby Current for Whole Device with Load.**

$$I_{S(OFF)} = f(T_J; V_S)$$

## Characterization Results

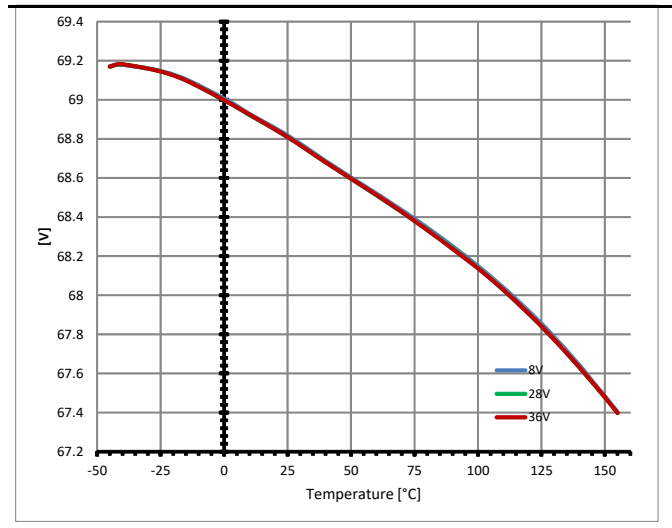
### 9.2 Power Stage

**P\_5.5.4**



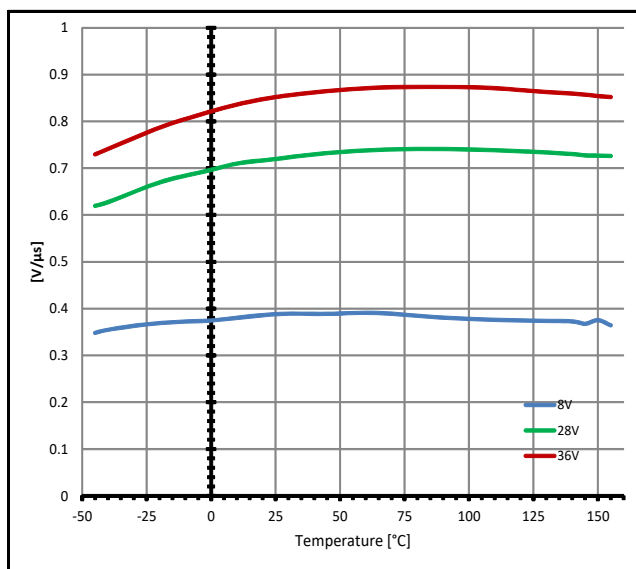
**Output Voltage Drop Limitation at Low Load Current**  
 $V_{DS(NL)} = f(T_J, V_S)$

**P\_5.5.5**



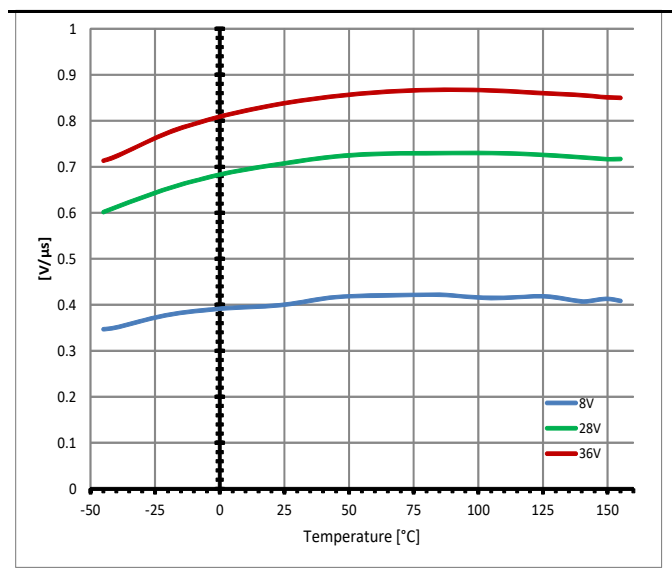
**Drain to Source Clamp Voltage  $V_{DS(AZ)} = f(T_J)$**

**P\_5.5.11**



**Slew Rate at Turn ON**  
 $dV/dt_{ON} = f(T_J, V_S), R_L = 4 \Omega$

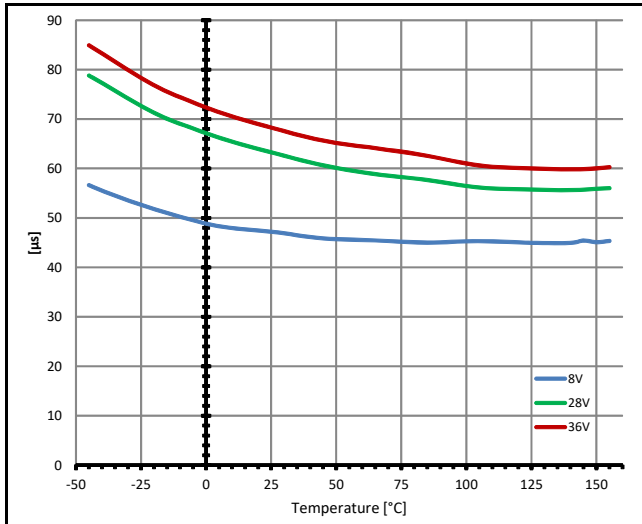
**P\_5.5.12**



**Slew Rate at Turn OFF**  
 $-dV/dt_{OFF} = f(T_J, V_S), R_L = 4 \Omega$

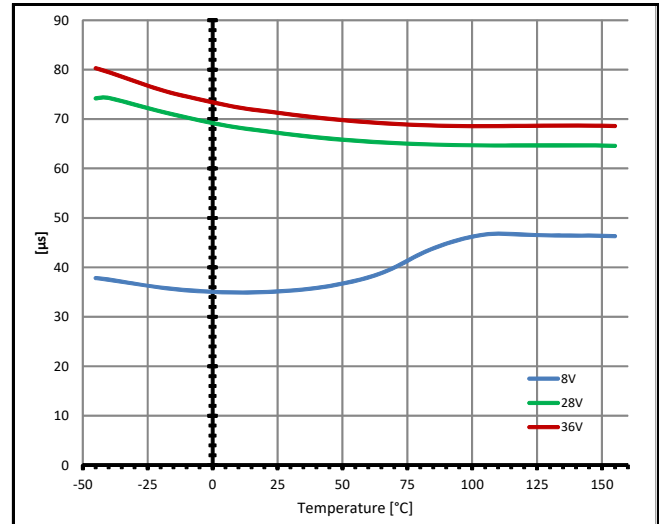
## Characterization Results

P\_5.5.14



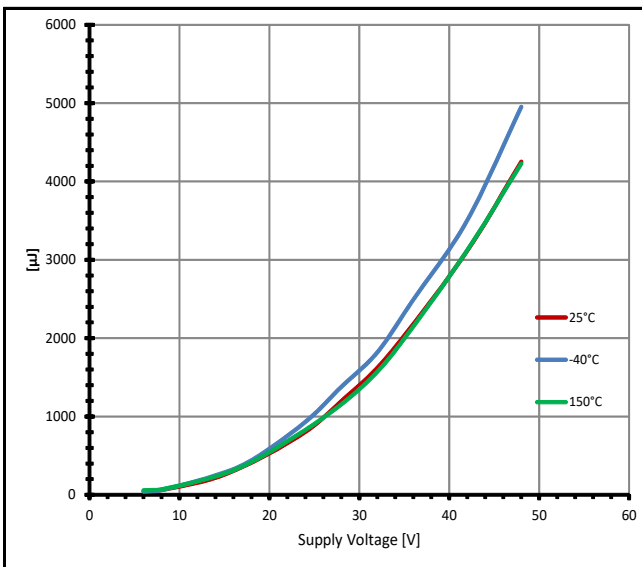
Turn ON  $T_{ON} = f(T_J; V_S), R_L = 4 \Omega$

P\_5.5.15



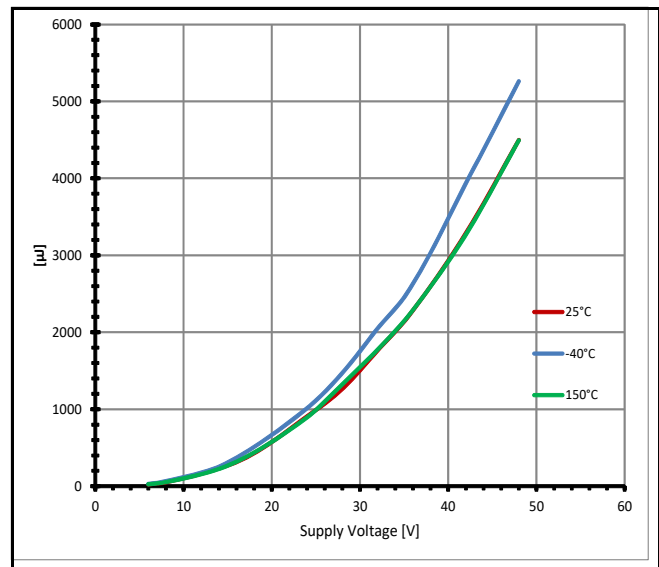
Turn OFF  $T_{OFF} = f(T_J; V_S), R_L = 4 \Omega$

P\_5.5.19



Switch ON Energy  $E_{ON} = f(T_J; V_S), R_L = 4 \Omega$

P\_5.5.20

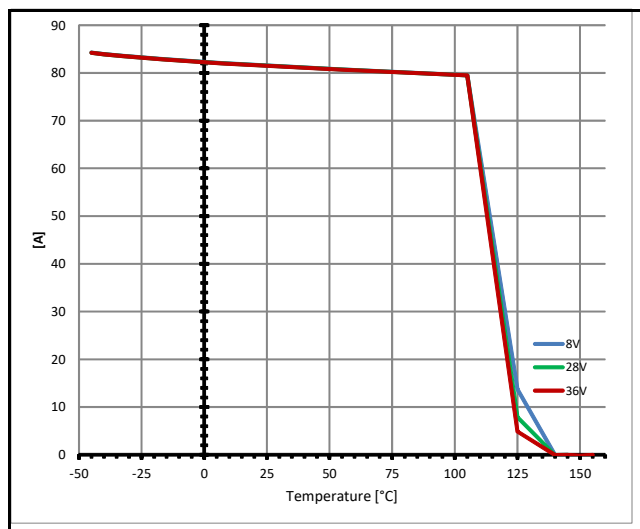


Switch OFF Energy  $E_{OFF} = f(T_J; V_S), R_L = 4 \Omega$

## Characterization Results

### 9.3 Protection Functions

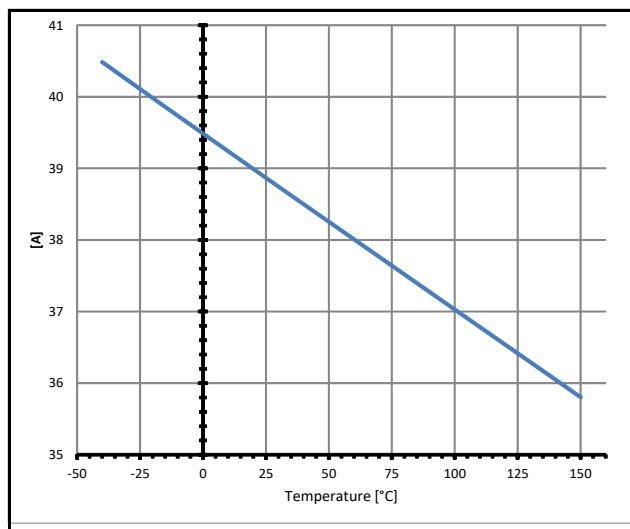
**P\_6.6.4**



**Overload Condition in the Low Voltage Area**

$$I_{L5(SC)} = f(T_J; V_S)$$

**P\_6.6.7**



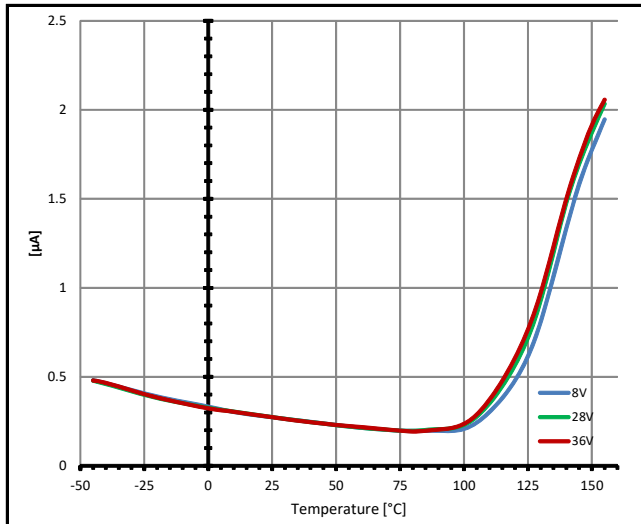
**Overload Condition in the High Voltage Area**

$$I_{L28(SC)} = f(T_J; V_S)$$

## Characterization Results

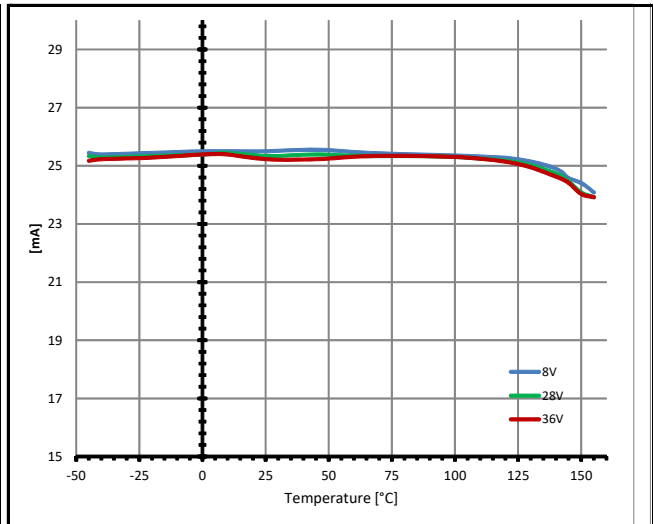
### 9.4 Diagnostic Mechanism

#### P\_7.5.2



**Current Sense at no Load**

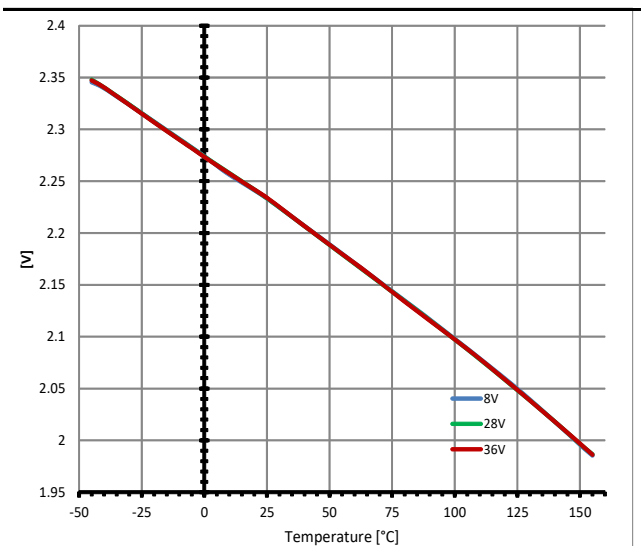
$$I_{IS} = f(T_J; V_S), I_L = 0$$



**Open Load Detection ON State Threshold**

$$I_{L(OL)} = f(T_J; V_S)$$

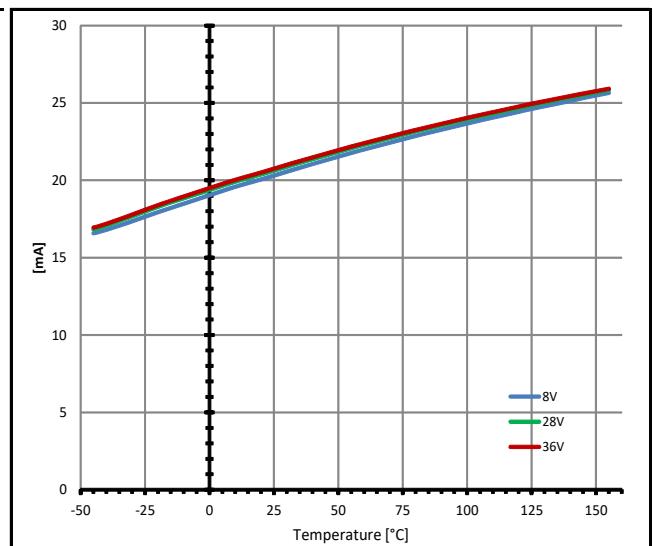
#### P\_7.5.6



**Sense Signal Maximum Voltage**

$$V_S - V_{IS(RANGE)} = f(T_J)$$

#### P\_7.5.7



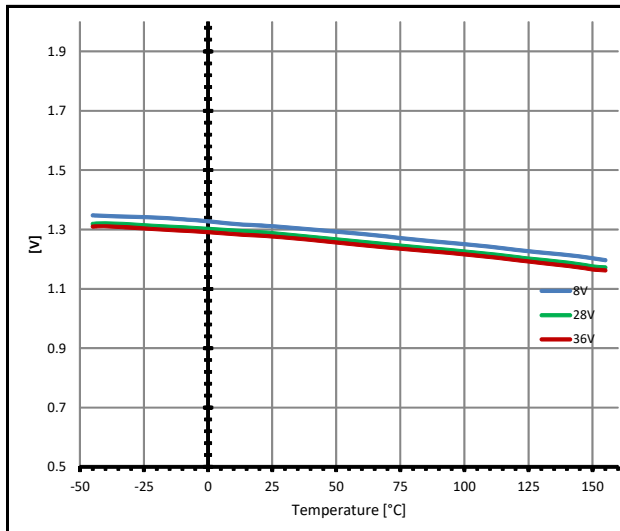
**Sense Signal Maximum Current in Fault Condition**

$$I_{IS(FAULT)} = f(T_J; V_S)$$

## Characterization Results

### 9.5 Input Pins

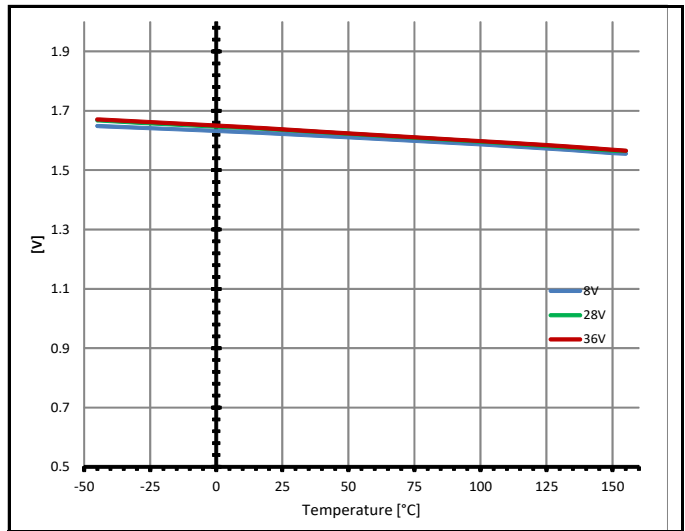
P\_8.4.1



Input Voltage Threshold

$$V_{IN(L)} = f(T_J; V_S)$$

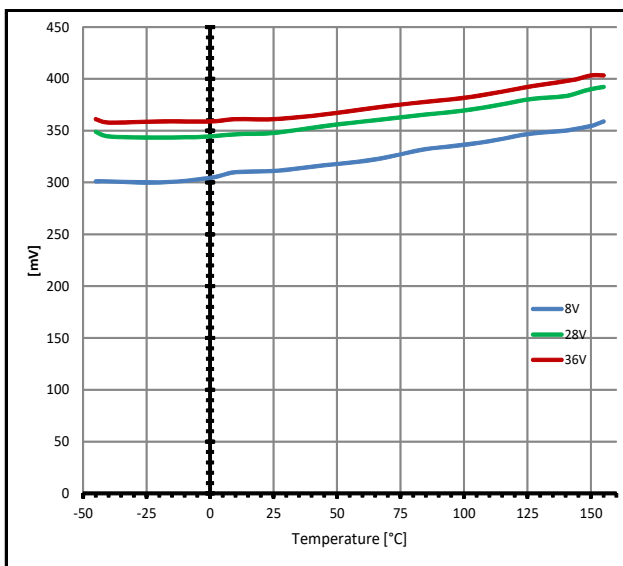
P\_8.4.2



Input Voltage Threshold

$$V_{IN(H)} = f(T_J; V_S)$$

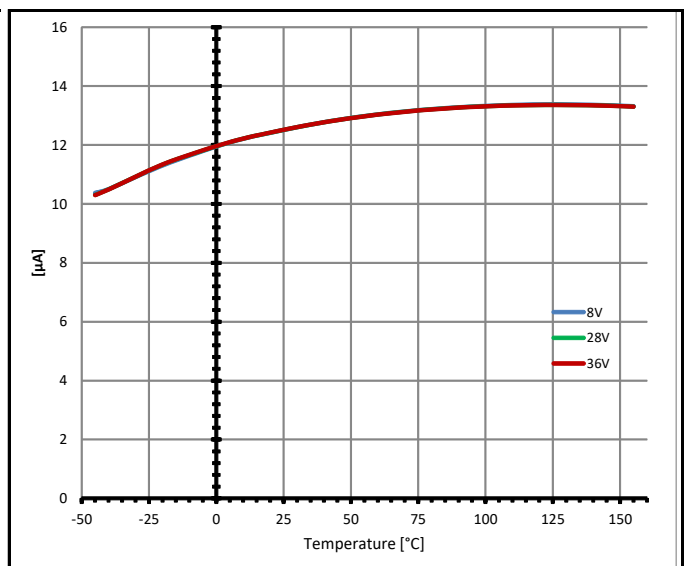
P\_8.4.3



Input Voltage Hysteresis

$$V_{IN(HYS)} = f(T_J; V_S)$$

P\_8.4.5



Input Current High Level

$$I_{IN(H)} = f(T_J)$$

The diagram illustrates a power management system. A **Voltage Regulator** is connected to  $V_{BAT}$  and provides a regulated output  $V_S$  to the **Microcontroller** and the **Load**. The **Microcontroller** is powered by  $V_{DD}$  and has a  $C_{VDD}$  capacitor. It controls the **Load** (represented by a **Bulb**) through a MOSFET driver. The driver consists of a MOSFET with its gate connected to the **Microcontroller** via  $R_{DEN}$  and  $R_{IN}$ . The MOSFET's source is connected to  $V_S$  and its drain is connected to the **Bulb** through  $R_{OUT}$ . The **Bulb** is also connected to  $V_S$  through  $R_{OUT}$ . The **Microcontroller** has an **ADC IN** pin connected to a sense resistor  $R_{SENSE}$  and a sense capacitor  $C_{SENSE}$ . The **Load** has a sense resistor  $R_{IS}$  and a sense capacitor  $C_{OUT}$ . The **Load** also has a diode  $D$  connected to  $V_S$  and a diode  $D_Z$  connected to  $V_S$ . The **Microcontroller** has a  $GND$  pin connected to the common ground.

## Application Information

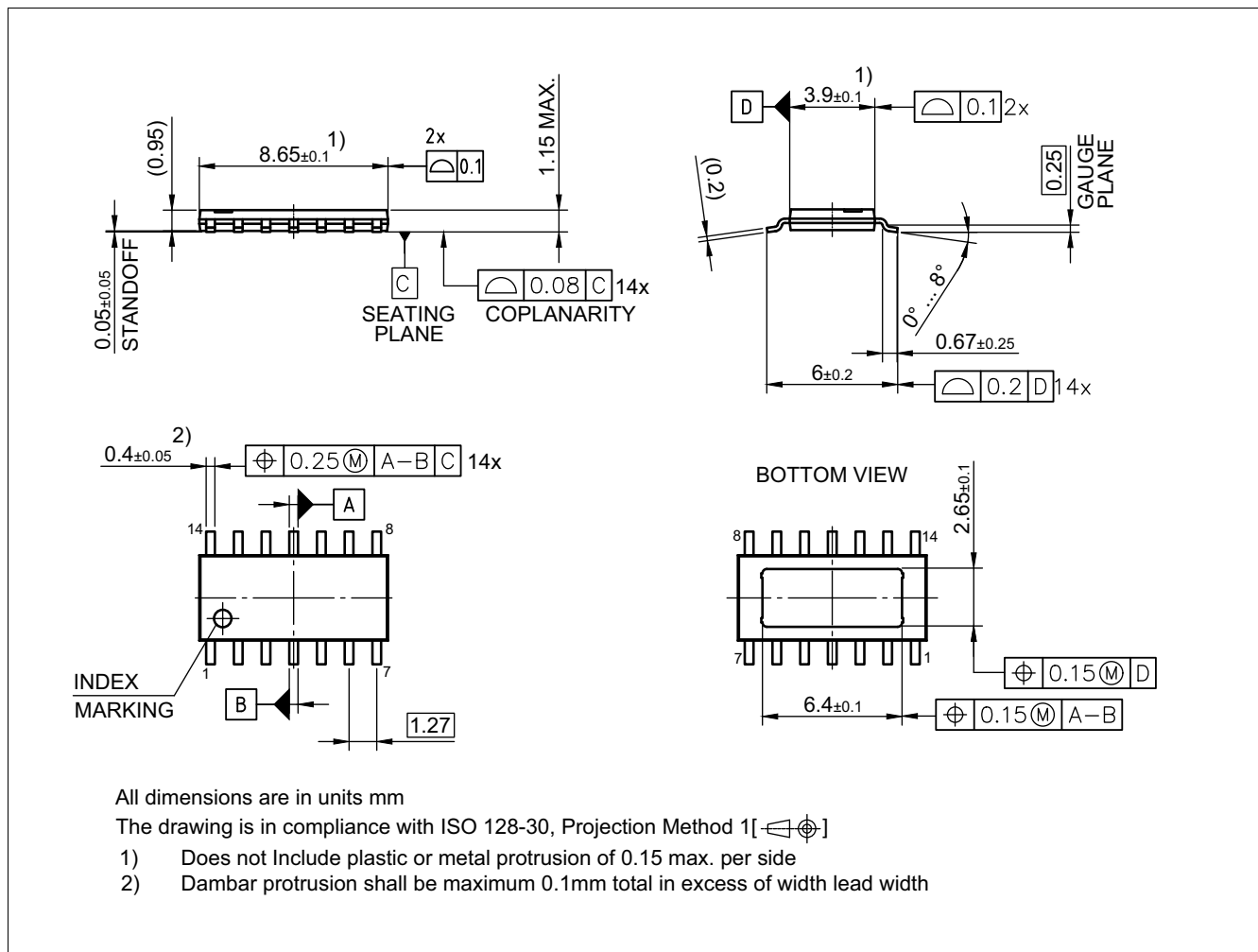
**Table 11** Bill of Material (cont'd)

| Reference   | Value            | Purpose                                                                           |
|-------------|------------------|-----------------------------------------------------------------------------------|
| $R_{OL}$    | 1.5 k $\Omega$   | Ensure polarization of the BTT6010-1ERB output during open load in OFF diagnostic |
| D           | BAS21            | Protection of the BTT6010-1ERB during reverse polarity                            |
| $R_{GND}$   | 27 $\Omega$      | To limit the GND current at a safe value during ISO pulse                         |
| Z           | 58 V Zener diode | Protection of the device during overvoltage                                       |
| T1          | Dual NPN/PNP     | Switch the battery voltage for open load in OFF diagnostic                        |
| $C_{SENSE}$ | 100 pF           | Sense signal filtering                                                            |
| $C_{VS}$    | 100 nF           | Filtering of the voltage spikes on the battery line                               |
| $C_{OUT}$   | 10 nF            | Protection of the BTT6010-1ERB during ESD and BCI                                 |

### 10.1 Further Application Information

- Please contact us to get the pin FMEA
- Existing App. Notes
- For further information you may visit [www.infineon.com](http://www.infineon.com)

## 11 Package Outlines



**Figure 30 PG-TDSO-14<sup>1)</sup>** (Plastic Dual Small Outline Package) (RoHS-Compliant)

### 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).

### Legal Disclaimer for Short-Circuit Capability

Infineon disclaims any warranties and liabilities, whether expressed or implied, for any short-circuit failures below the threshold limit.

### Further information on packages

<https://www.infineon.com/packages>

1) Dimensions in mm

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**Revision History**

## **12 Revision History**

| <b>Version</b> | <b>Date</b> | <b>Changes</b>            |
|----------------|-------------|---------------------------|
| 1.00           | 2019-03-09  | Creation of the datasheet |

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**Edition 2019-03-09**

**Published by**

**Infineon Technologies AG**

**81726 Munich, Germany**

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**Document reference**

**BTT6010-1ERB**

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