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PROFET™+ 24V

BTT6020-1EKA

Smart High-Side Power Switch
Single Channel, 20mΩ

Data Sheet

PROFET™+ 24V
Rev. 1.1, 2015-03-04

Automotive Power

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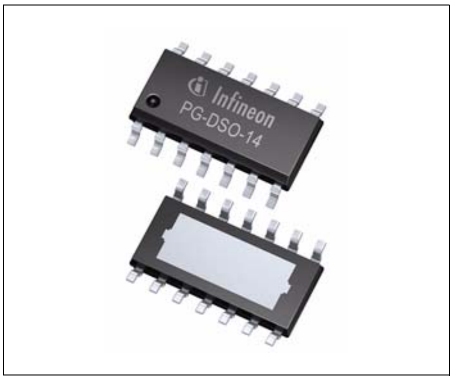
Smart High-Side Power Switch **BTT6020-1EKA**

1 Overview



PG-DSO-14-47 EP

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 24V truck and transportation system

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 from load ground
- Very low power DMOS leakage current in OFF state
- Green product (RoHS compliant)
- AEC qualified

Description

The BTT6020-1EKA is a 20 mΩ single channel Smart High-Side Power Switch, embedded in a PG-DSO-14-47 EP, 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 1 x 70W 24V, 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	$V_{S(LD)}$	65 V
Maximum ON state resistance at T_J = 150 °C	$R_{DS(ON)}$	40 mΩ
Nominal load current	$I_{L(NOM)}$	7 A
Typical current sense ratio	k_{ILIS}	2950
Minimum current limitation	$I_{L5(SC)}$	70 A
Maximum standby current with load at T_J = 25 °C	$I_{S(OFF)}$	0.5 µA

Type	Package	Marking
BTT6020-1EKA	PG-DSO-14-47 EP	BTT6020-1EKA

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

2 Block Diagram

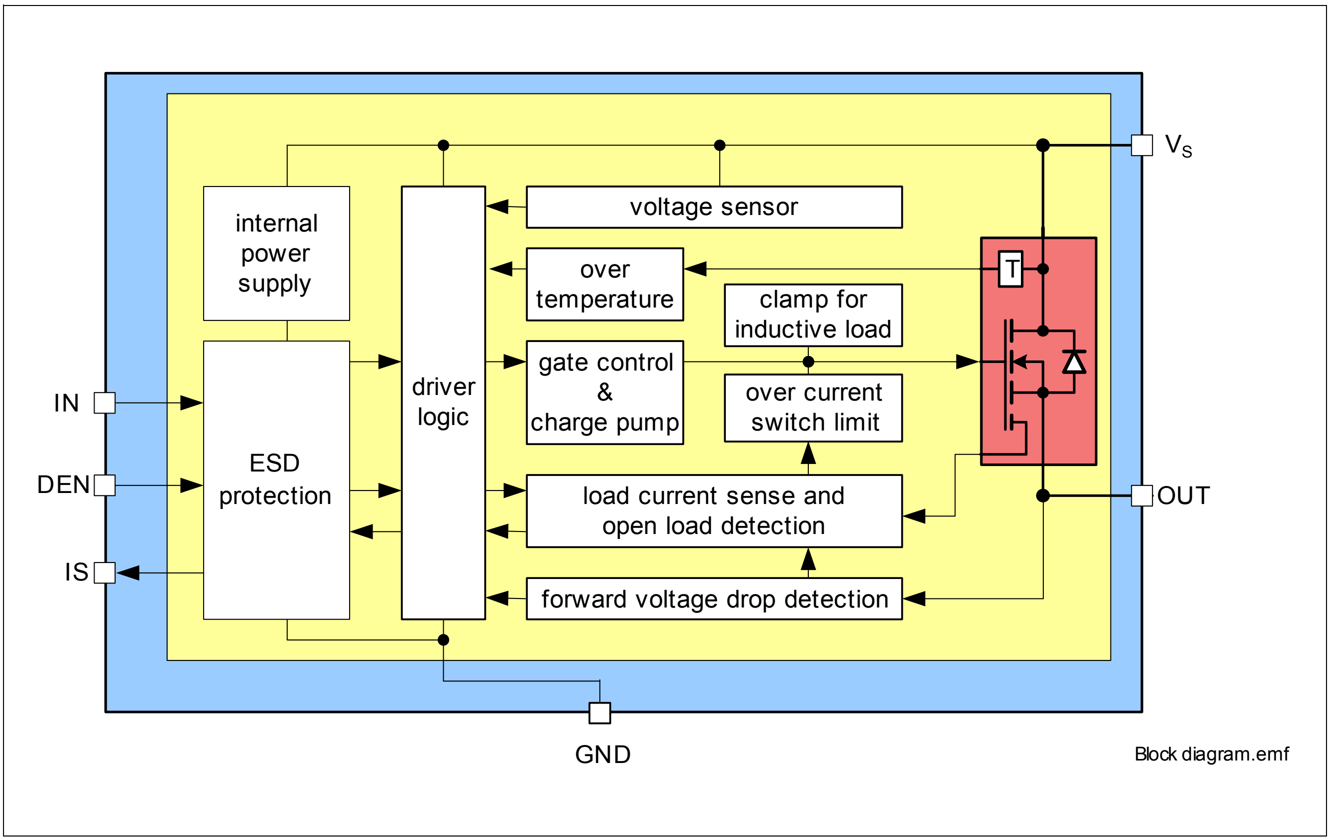


Figure 1 Block Diagram for the BTT6020-1EKA

3 Pin Configuration

3.1 Pin Assignment

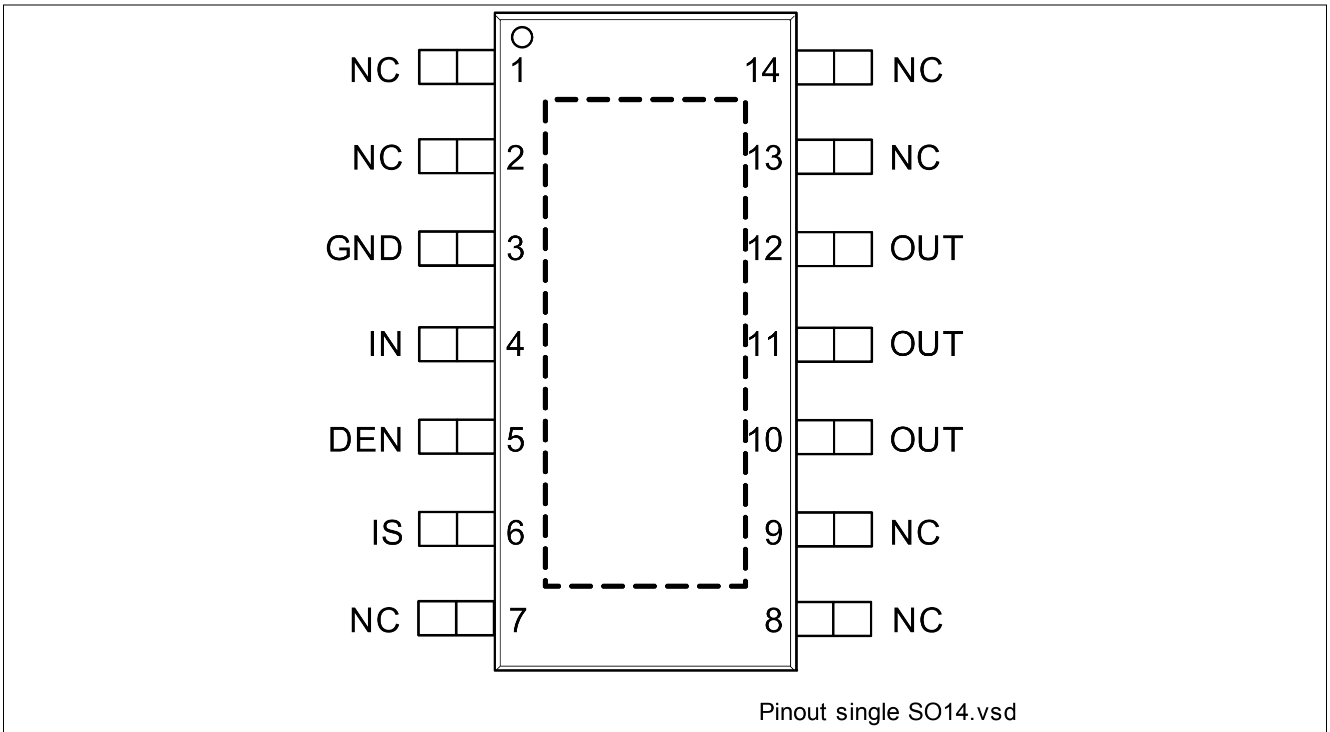


Figure 2 Pin Configuration

3.2 Pin Definitions and Functions

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

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.

3.3 Voltage and Current Definition

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

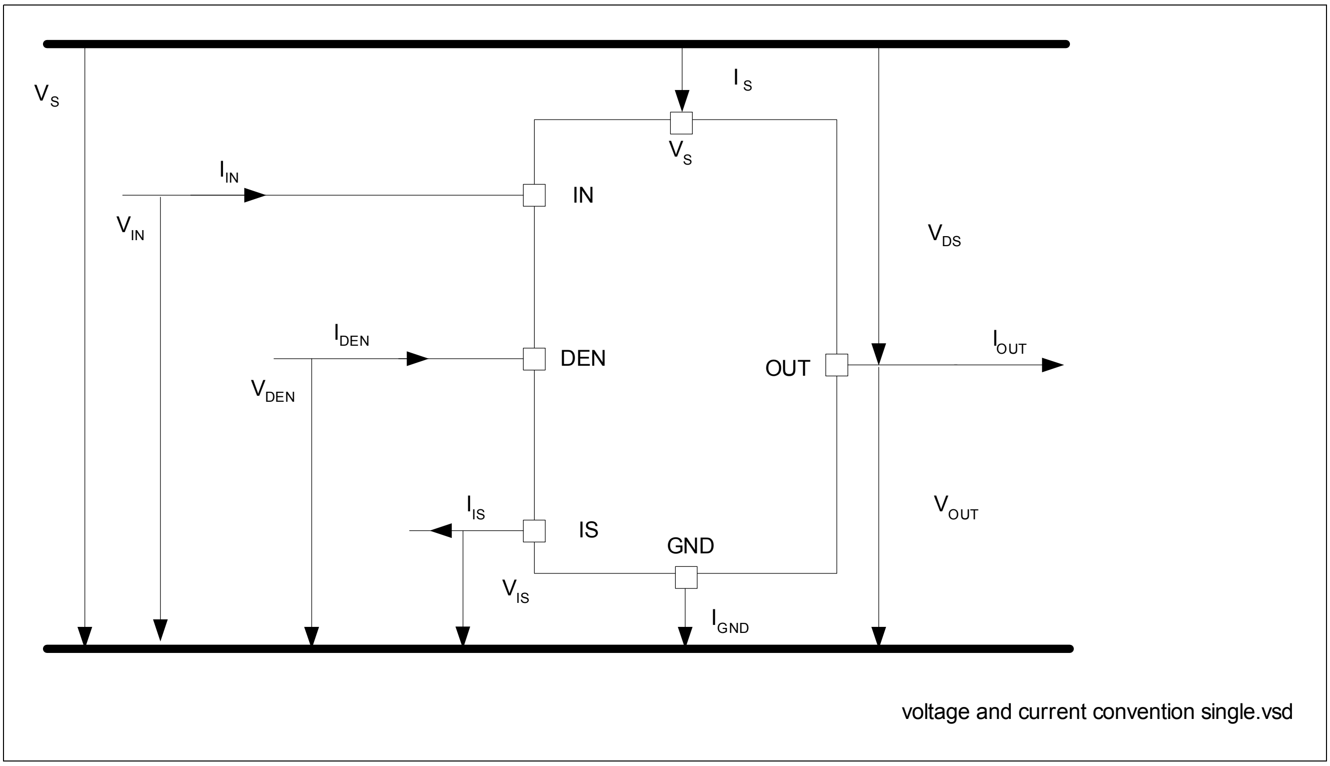


Figure 3 Voltage and Current Definition

4 General Product Characteristics

4.1 Absolute Maximum Ratings

Table 2 Absolute Maximum Ratings [1)]

T_J = -40 °C to +150°C; (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note / Test Condition	Number
		Min.	Typ.	Max.			
Supply Voltages							
Supply voltage	V_S	-0.3	–	48	V	–	P_4.1.1
Reverse polarity voltage	$-V_{S(REV)}$	0	–	28	V	t < 2 min T_A = 25 °C $R_L \geq 6\ \Omega$ R_{GND} = 150 Ω	P_4.1.2
Supply voltage for short circuit protection	$V_{BAT(SC)}$	0	–	36	V	R_{ECU} = 20 mΩ R_{Cable}= 16 mΩ/m L_{Cable}= 1 µH/m, l = 0 or 5 m See **Chapter 6** and **Figure 52**	P_4.1.3
Supply voltage for Load dump protection	$V_{S(LD)}$	–	–	65	V	[2)] R_I = 2 Ω R_L = 6 Ω	P_4.1.12
Short Circuit Capability							
Permanent short circuit IN pin toggles	n_{RSC1}		–	100	k cycles	[3)] V_{Supply} = 28V	P_4.1.4
Input Pins							
Voltage at INPUT pin	V_{IN}	-0.3 –	–	6 7	V	– t < 2 min	P_4.1.13
Current through INPUT pin	I_{IN}	-2	–	2	mA	–	P_4.1.14
Voltage at DEN pin	V_{DEN}	-0.3 –	–	6 7	V	– t < 2 min	P_4.1.15
Current through DEN pin	I_{DEN}	-2	–	2	mA	–	P_4.1.16
Sense Pin							
Voltage at IS pin	V_{IS}	-0.3	–	V_S	V	–	P_4.1.19
Current through IS pin	I_{IS}	-25	–	50	mA	–	P_4.1.20
Power Stage							
Load current	$\vert I_L \vert$	–	–	$I_{L(LIM)}$	A	–	P_4.1.21
Power dissipation (DC)	P_{TOT}	–	–	1.6	W	T_A = 85 °C T_J < 150 °C	P_4.1.22
Maximum energy dissipation Single pulse	E_{AS}	–	–	150	mJ	$I_{L(0)}$ = 7 A $T_{J(0)}$ = 150 °C V_S = 28 V	P_4.1.23
Voltage at power transistor	V_{DS}	–	–	65	V	–	P_4.1.26

Table 2 Absolute Maximum Ratings (cont'd)[1]

T_J = -40 °C to +150°C; (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note / Test Condition	Number
		Min.	Typ.	Max.			
Currents							
Current through ground pin	I_{GND}	-20 -200	–	20 20	mA	– t < 2 min	P_4.1.27
Temperatures							
Junction temperature	T_J	-40	–	150	°C	–	P_4.1.28
Storage temperature	T_{STG}	-55	–	150	°C	–	P_4.1.30
ESD Susceptibility							
ESD susceptibility (all pins)	V_{ESD}	-2	–	2	kV	[4] HBM	P_4.1.31
ESD susceptibility OUT Pin vs. GND and V_S connected	V_{ESD}	-4	–	4	kV	[4] HBM	P_4.1.32
ESD susceptibility	V_{ESD}	-500	–	500	V	[5] CDM	P_4.1.33
ESD susceptibility pin (corner pins)	V_{ESD}	-750	–	750	V	[5] 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 at the end of this document.
4) ESD susceptibility HBM according to ANSI/ESDA/JEDEC JS-001
5) ESD susceptibility, Charge Device Model "CDM" ESDA STM5.3.1 or ANSI/ESD S.5.3.1

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.*

4.2 Functional Range

Table 3 Functional Range T_J = -40 °C to +150°C; (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note / Test Condition	Number
		Min.	Typ.	Max.			
Nominal operating voltage	V_{NOM}	8	28	36	V	–	P_4.2.1
Extended operating voltage	$V_{S(OP)}$	5	–	48	V	[2] V_{IN} = 4.5 V R_L = 6 Ω V_{DS} < 0.5 V See **Figure 15**	P_4.2.2
Minimum functional supply voltage	$V_{S(OP)\_MIN}$	3.8	4.3	5	V	[1] V_{IN} = 4.5 V R_L = 6 Ω From I_{OUT} = 0 A to V_{DS} < 0.5 V; See **Figure 15**	P_4.2.3
Undervoltage shutdown	$V_{S(UV)}$	–	3.5	4.1	V	[1] V_{IN} = 4.5 V V_{DEN} = 0 V R_L = 6 Ω From V_{DS} < 1 V; to I_{OUT} = 0 A See **Figure 15** See **Figure 30**	P_4.2.4
Undervoltage shutdown hysteresis	$V_{S(UV)\_HYS}$	–	850	–	mV	[2] –	P_4.2.13
Operating current channel active	I_{GND_1}	–	4.8	9	mA	V_{IN} = 5.5 V V_{DEN} = 5.5 V Device in $R_{DS(ON)}$ V_S = 36 V See **Figure 31**	P_4.2.5
Standby current for whole device with load (ambiente)	$I_{S(OFF)}$	–	0.1	0.5	µA	[1] V_S = 36 V V_{OUT} = 0 V V_{IN} floating V_{DEN} floating $T_J \leq$ 85 °C See **Figure 32**	P_4.2.7
Maximum standby current for whole device with load	$I_{S(OFF)\_150}$	–	4	15	µA	V_S = 36 V V_{OUT} = 0 V V_{IN} floating V_{DEN} floating T_J = 150 °C See **Figure 32**	P_4.2.10
Standby current for whole device with load, diagnostic active	$I_{S(OFF\_DEN)}$	–	0.5	–	mA	[2] V_S = 36 V V_{OUT} = 0 V V_{IN} floating V_{DEN} = 5.5 V	P_4.2.8

1) Test at T_J = -40°C only

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

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 4 Thermal Resistance

Parameter	Symbol	Values			Unit	Note / Test Condition	Number
		Min.	Typ.	Max.			
Junction to soldering point	R_{thJS}	–	5	–	K/W	[1]	P_4.3.1
Junction to ambient	R_{thJA}	–	27	–	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; 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 70µm Cu, 2 x 35 µm 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

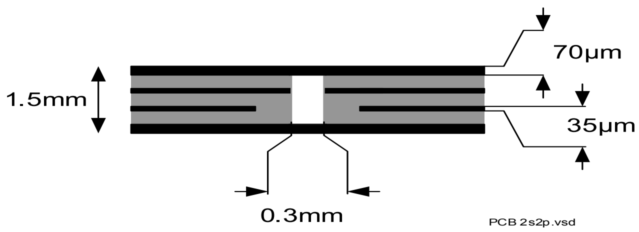


Figure 4 2s2p PCB Cross Section

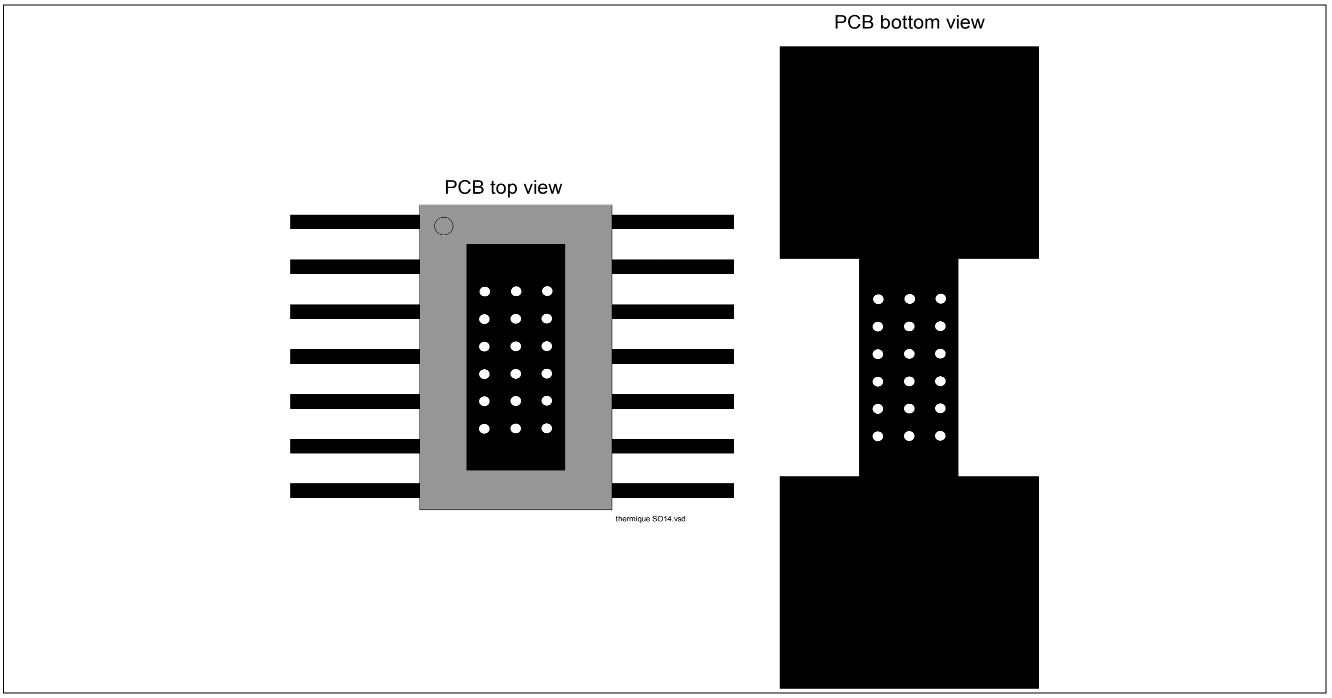


Figure 5 PC Board Top and Bottom View for Thermal Simulation with 600 mm² Cooling Area

4.3.2 Thermal Impedance

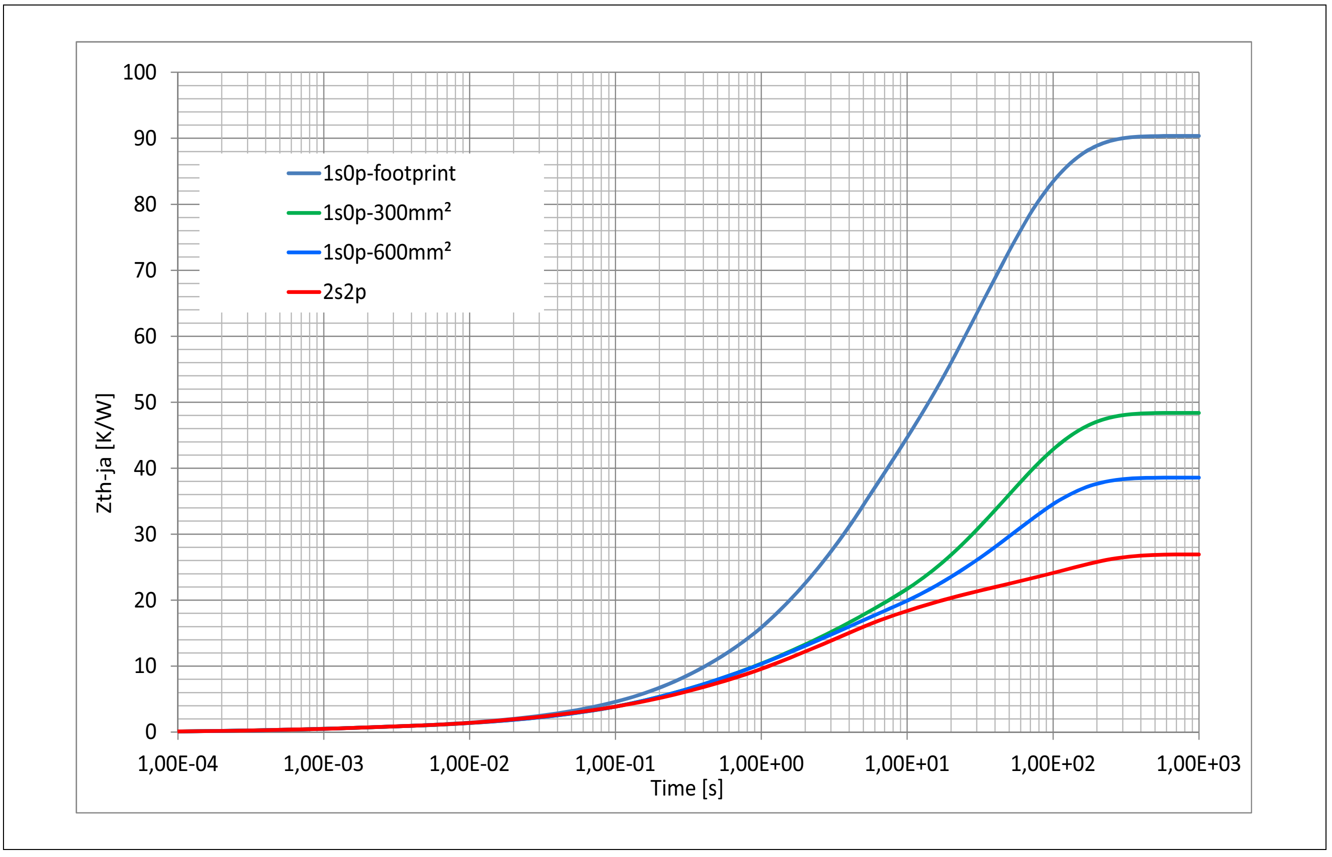


Figure 6 Typical Thermal Impedance. 2s2p set up according Figure 4

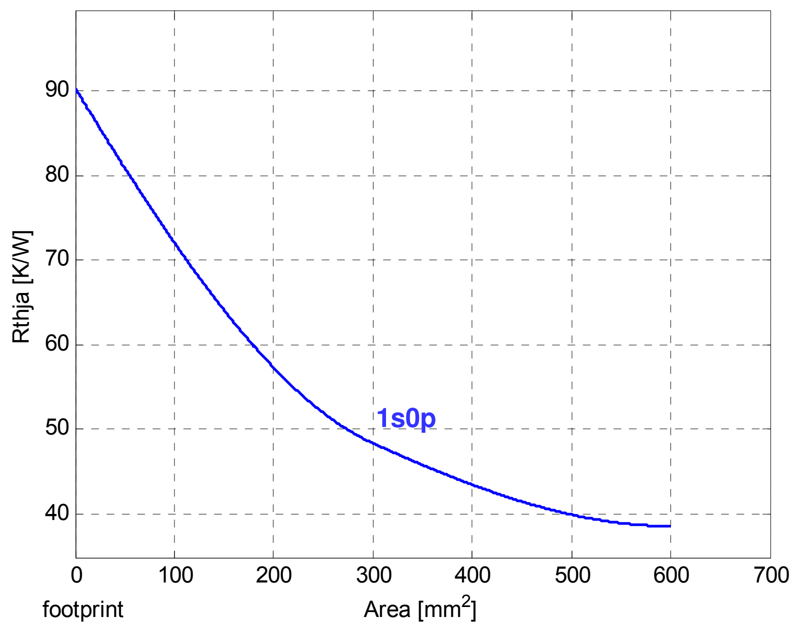


Figure 7 Typical Thermal Resistance. PCB set up 1s0p

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**.

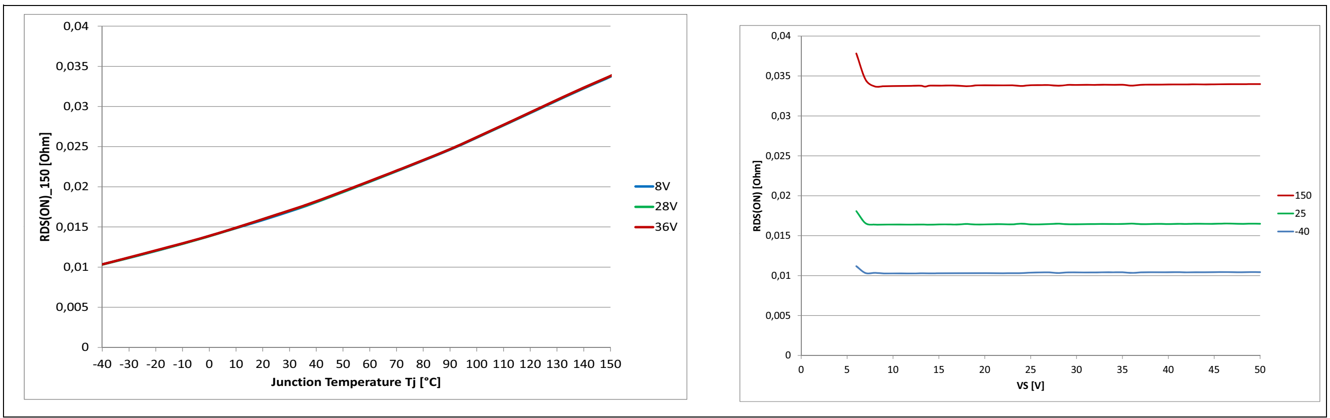


Figure 8 Typical ON-state Resistance

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.

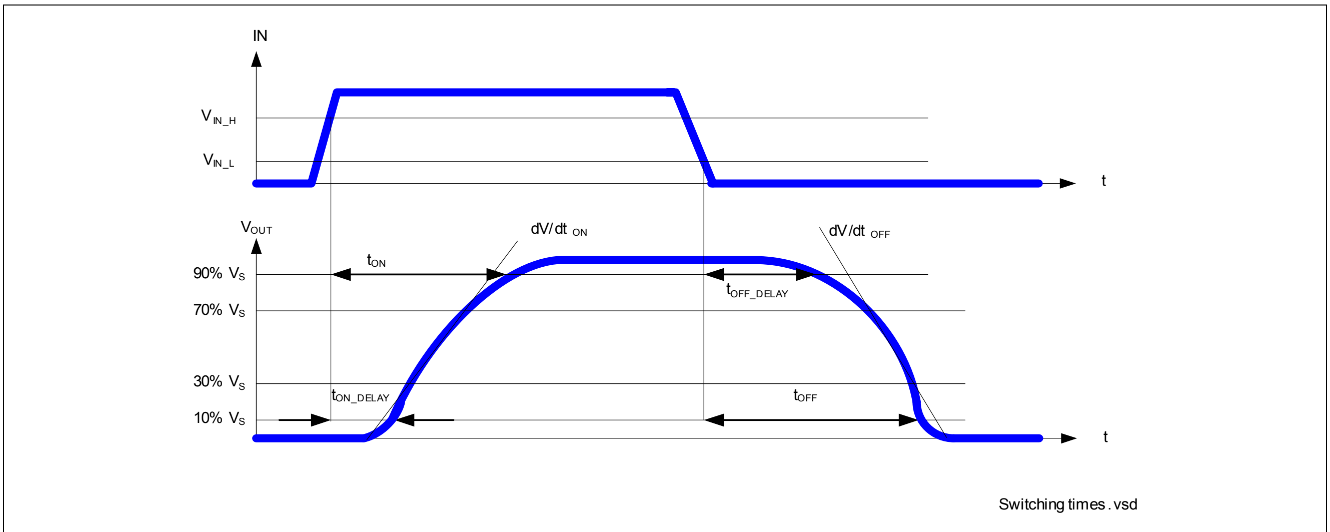


Figure 9 Switching a Resistive Load Timing

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.

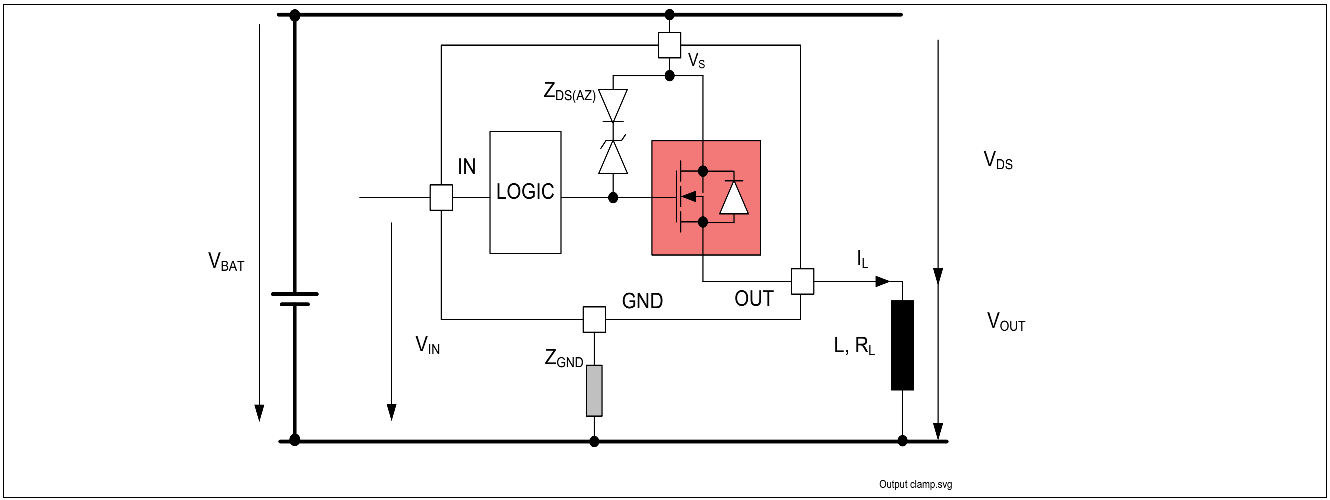


Figure 10 Output Clamp

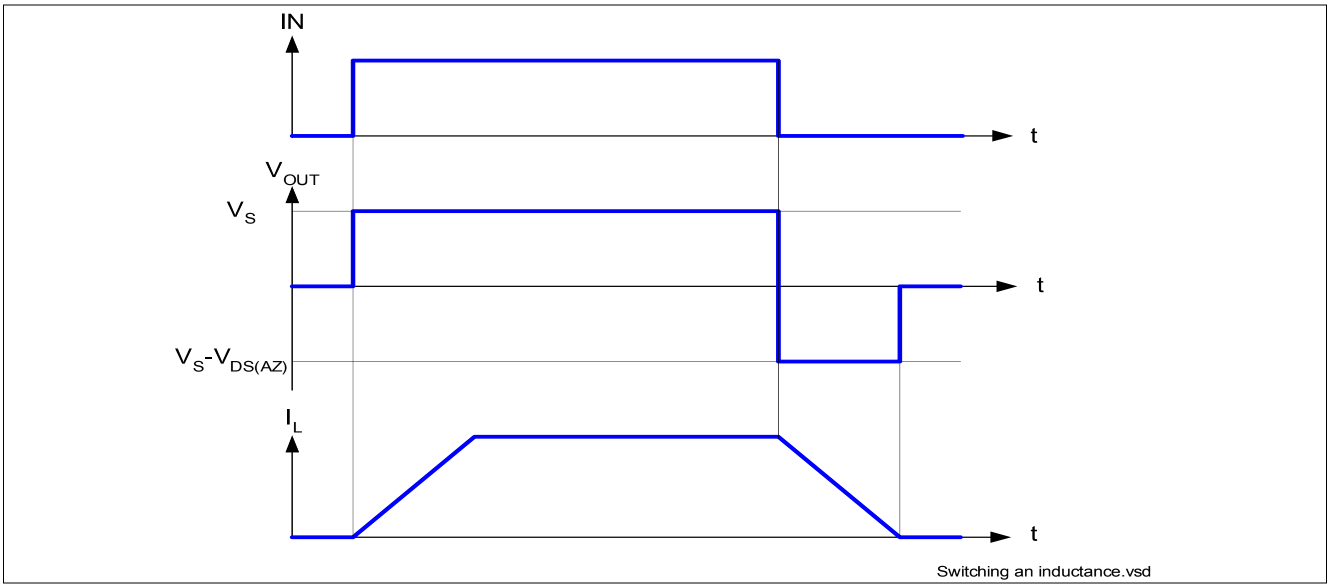


Figure 11 Switching an Inductive Load Timing

5.3.2 Maximum Load Inductance

During demagnetization of inductive loads, energy has to be dissipated in the BTT6020-1EKA. This energy can be calculated with following equation:

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

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

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

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.

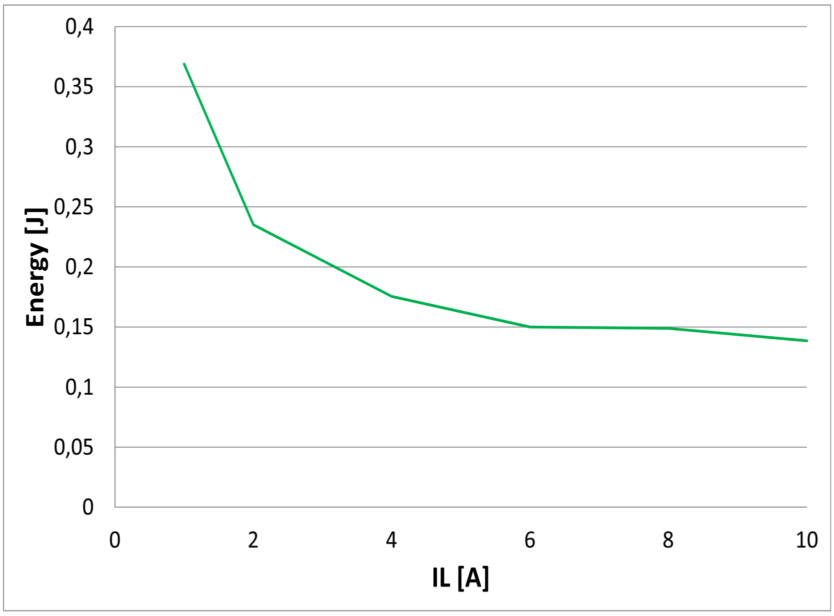


Figure 12 Maximum Energy Dissipation Single Pulse, T_{J_START} = 150 °C; V_S = 28V

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 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.

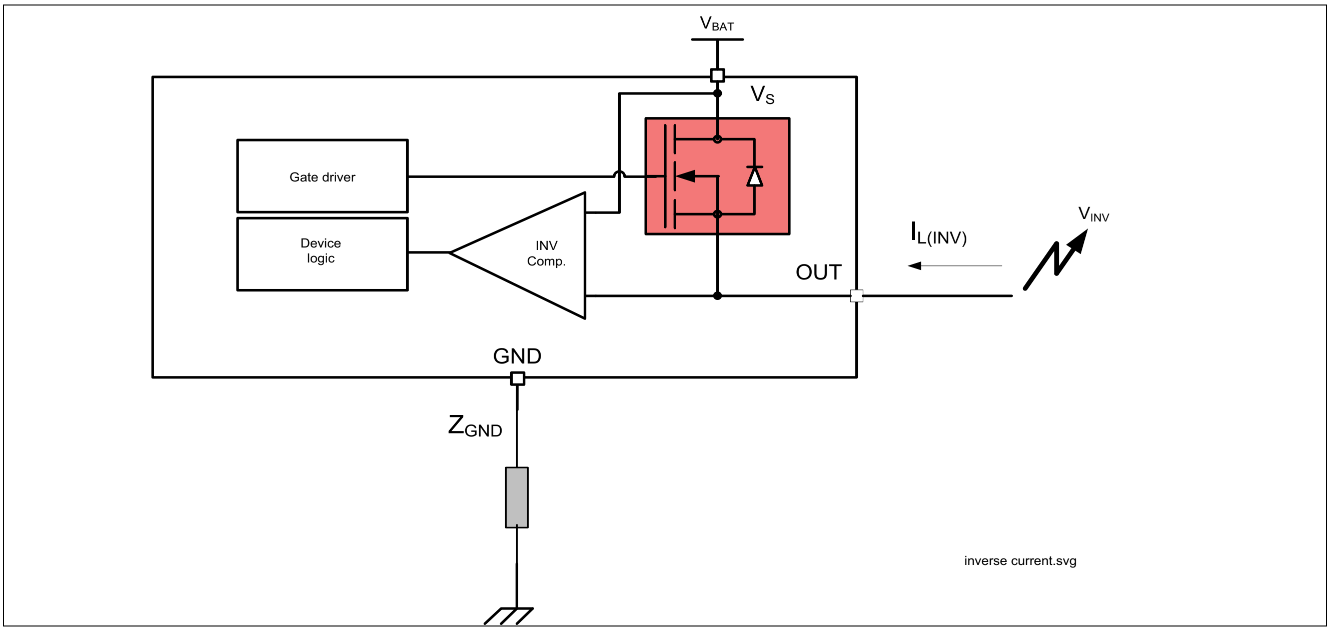


Figure 13 Inverse Current Circuitry

5.5 Electrical Characteristics Power Stage

Table 5 Electrical Characteristics: Power Stage

V_S = 8 V to 36 V, T_J = -40 °C to +150°C (unless otherwise specified).
Typical values are given at V_S = 28 V, T_J = 25 °C

Parameter	Symbol	Values			Unit	Note / Test Condition	Number
		Min.	Typ.	Max.			
ON-state resistance per channel	$R_{DS(ON)\_150}$	25	35	40	mΩ	$I_L = I_{L4}$ = 7 A V_{IN} = 4.5 V T_J = 150 °C See **Figure 8**	P_5.5.1
ON-state resistance per channel	$R_{DS(ON)\_25}$	–	20	–	mΩ	1) T_J = 25 °C	P_5.5.21
Nominal load current	$I_{L(NOM)}$	–	7	–	A	1) T_A = 85 °C T_J < 150 °C	P_5.5.2
Output voltage drop limitation at small load currents	$V_{DS(NL)}$	–	10	22	mV	$I_L = I_{L0}$ = 50 mA See **Figure 33**	P_5.5.4
Drain to source clamping voltage $V_{DS(AZ)} = [V_S - V_{OUT}]$	$V_{DS(AZ)}$	66	70	75	V	I_{DS} = 20 mA See **Figure 11** See **Figure 34**	P_5.5.5
Output leakage current $T_J \leq$ 85 °C	$I_{L(OFF)}$	–	0.05	0.5	µA	2) V_{IN} floating V_{OUT} = 0 V $T_J \leq$ 85 °C	P_5.5.6
Output leakage current T_J = 150 °C	$I_{L(OFF)\_150}$	–	4	10	µA	V_{IN} floating V_{OUT} = 0 V T_J = 150 °C	P_5.5.8
Slew rate 30% to 70% V_S	dV/dt_{ON}	0.3	0.8	1.4	V/µs	R_L = 6 Ω V_S = 28 V See **Figure 9** See **Figure 35** See **Figure 36** See **Figure 37** See **Figure 38** See **Figure 39**	P_5.5.11
Slew rate 70% to 30% V_S	$-dV/dt_{OFF}$	0.3	0.8	1.4	V/µs		P_5.5.12
Slew rate matching $dV/dt_{ON} - dV/dt_{OFF}$	$\Delta dV/dt$	-0.15	0	0.15	V/µs		P_5.5.13
Turn-ON time to V_{OUT} = 90% V_S	t_{ON}	20	100	150	µs		P_5.5.14
Turn-OFF time to V_{OUT} = 10% V_S	t_{OFF}	20	100	150	µs		P_5.5.15
Turn-ON / OFF matching $t_{OFF} - t_{ON}$	Δt_{SW}	-50	0	50	µs		P_5.5.16
Turn-ON time to V_{OUT} = 10% V_S	t_{ON_delay}	–	30	70	µs		P_5.5.17
Turn-OFF time to V_{OUT} = 90% V_S	t_{OFF_delay}	–	30	70	µs		P_5.5.18

Table 5 Electrical Characteristics: Power Stage (cont'd)

V_S = 8 V to 36 V, T_J = -40 °C to +150°C (unless otherwise specified).
Typical values are given at V_S = 28 V, T_J = 25 °C

Parameter	Symbol	Values			Unit	Note / Test Condition	Number
		Min.	Typ.	Max.			
Switch ON energy	E_{ON}	–	0.6	–	mJ	[1] R_L = 6 Ω V_{OUT} = 90% V_S V_S = 36 V See **Figure 40**	P_5.5.19
Switch OFF energy	E_{OFF}	–	0.7	–	mJ	[1] R_L = 6 Ω V_{OUT} = 10% V_S V_S = 36 V See **Figure 41**	P_5.5.20

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

2) Test at T_J = -40°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 BTT6020-1EKA 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.

Z_{GND} is recommended to be a resistor in series to a diode.

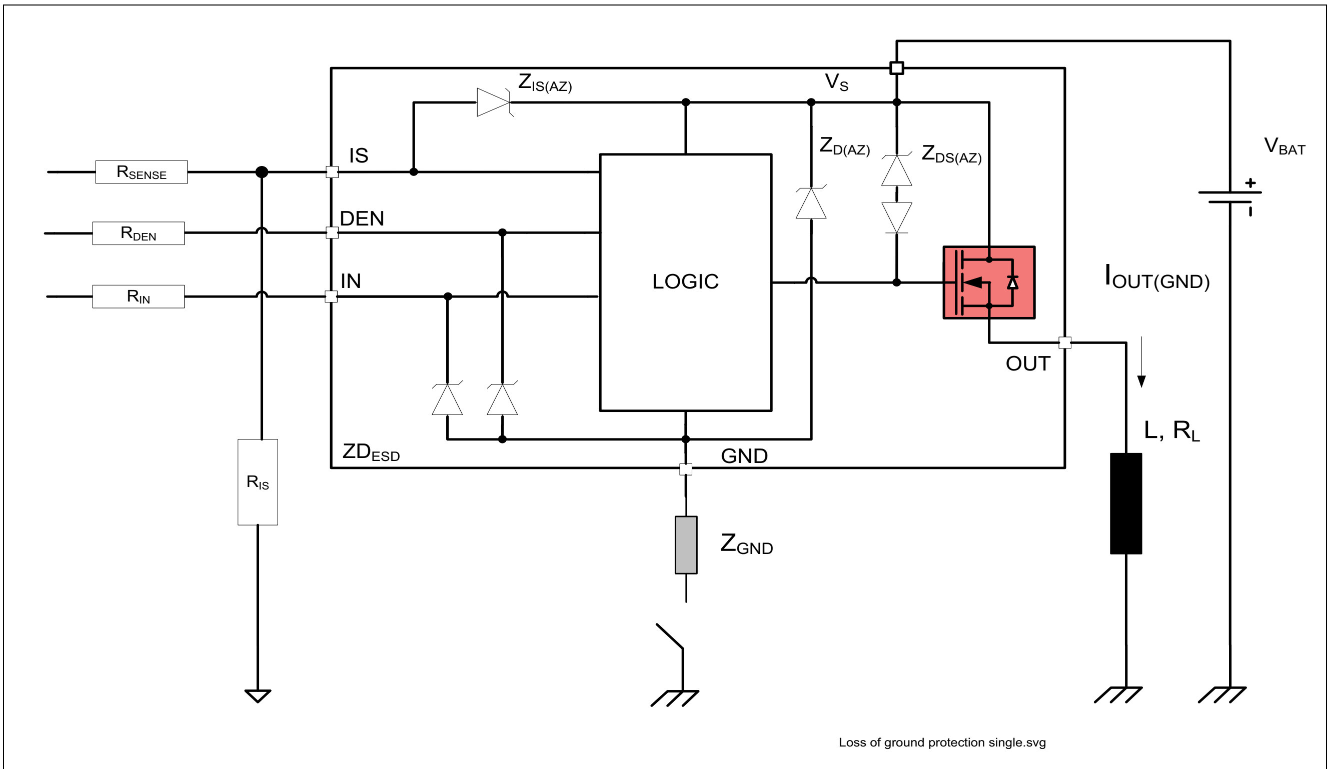


Figure 14 Loss of Ground Protection with External Components

6.2 Undervoltage Protection

Between $V_{S(UV)}$ and $V_{S(OP)}$, the under voltage mechanism is triggered. $V_{S(OP)}$ represents the minimum voltage where the switching ON and OFF can takes 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** sketches the undervoltage mechanism.

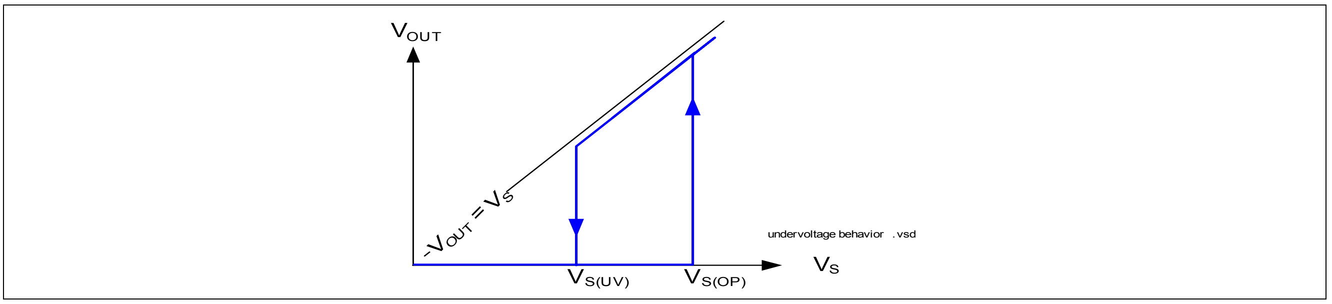


Figure 15 Undervoltage Behavior

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 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 BTT6020-1EKA remains ON. In the case the BTT6020-1EKA 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.

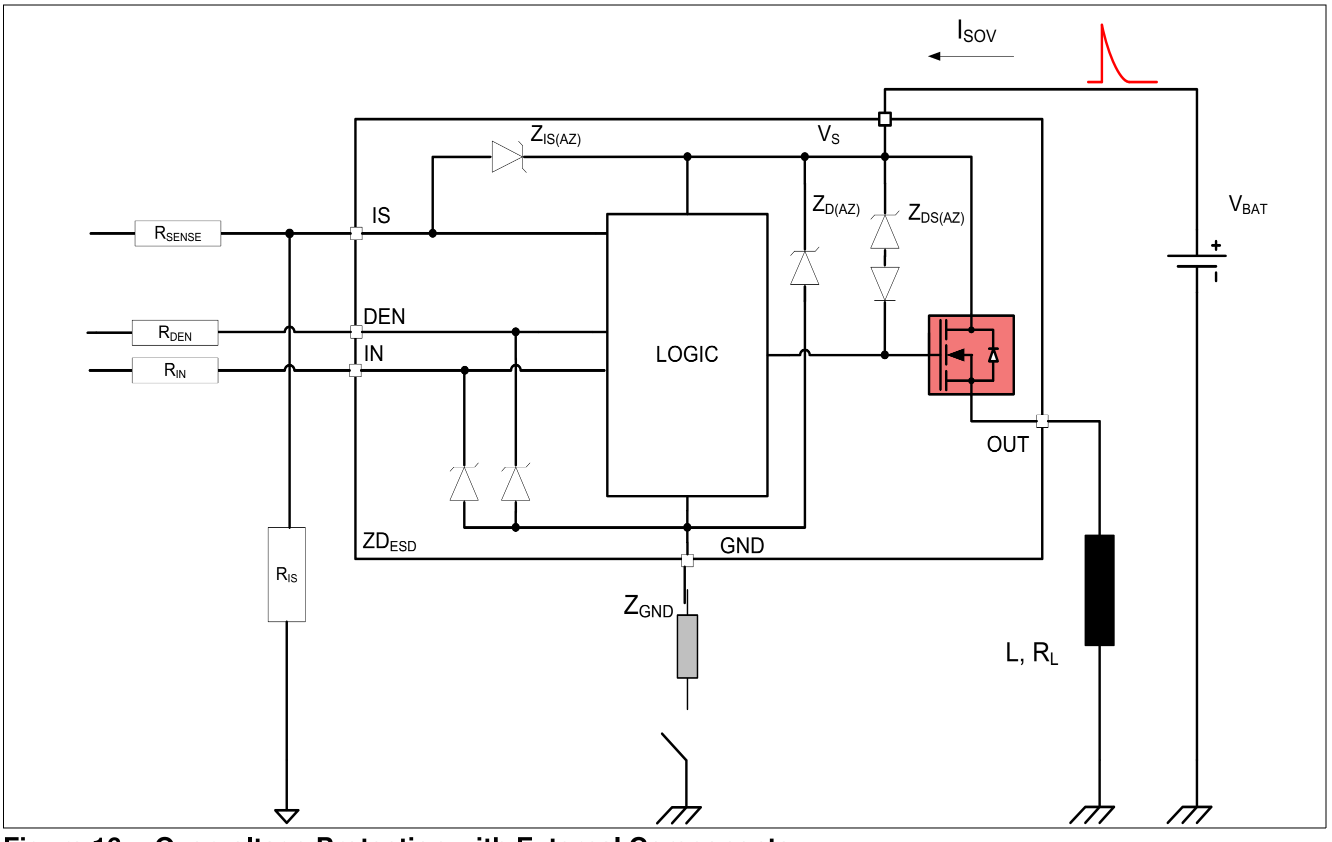


Figure 16 Overvoltage Protection with External Components

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_{GND} resistor is used to limit the current in the Zener protection of the device. Resistors R_{DEN} and R_{IN} are used to limit the current in the logic of the device and in the ESD protection stage. R_{SENSE} is used to limit the current in the sense transistor which behaves as a diode. The recommended value for R_{DEN} = R_{IN} = R_{SENSE} = 10 kΩ. Z_{GND} is recommended to be a resistor in series to a diode.

During reverse polarity, no protection functions are available.

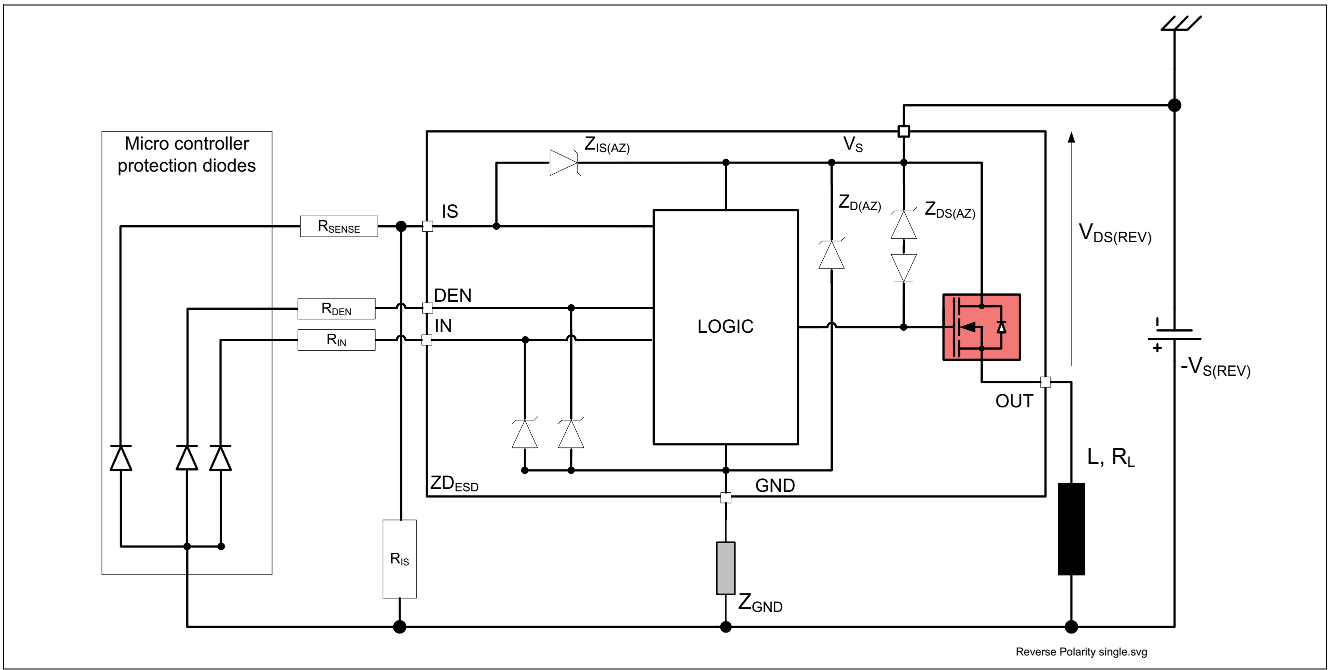


Figure 17 Reverse Polarity Protection with External Components

6.5 Overload Protection

In case of overload, such as high inrush of cold lamp filament, or short circuit to ground, the BTT6020-1EKA 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.

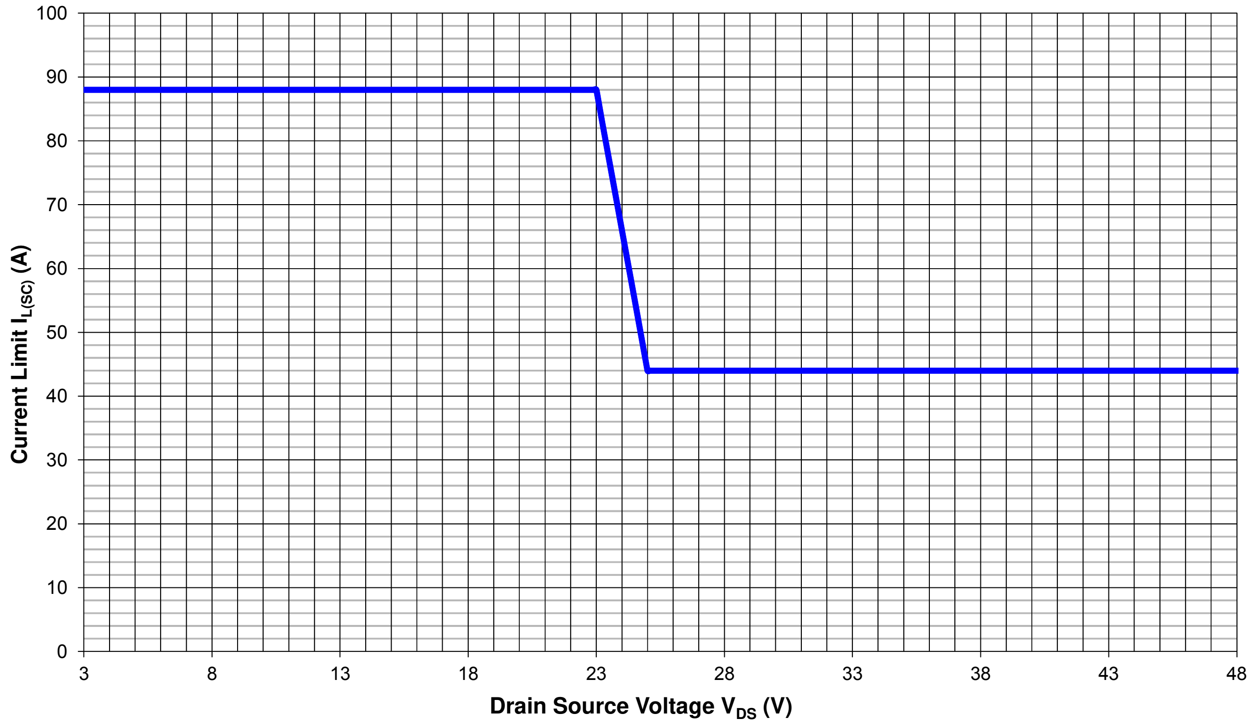


Figure 18 Current Limitation (typical behavior)

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).

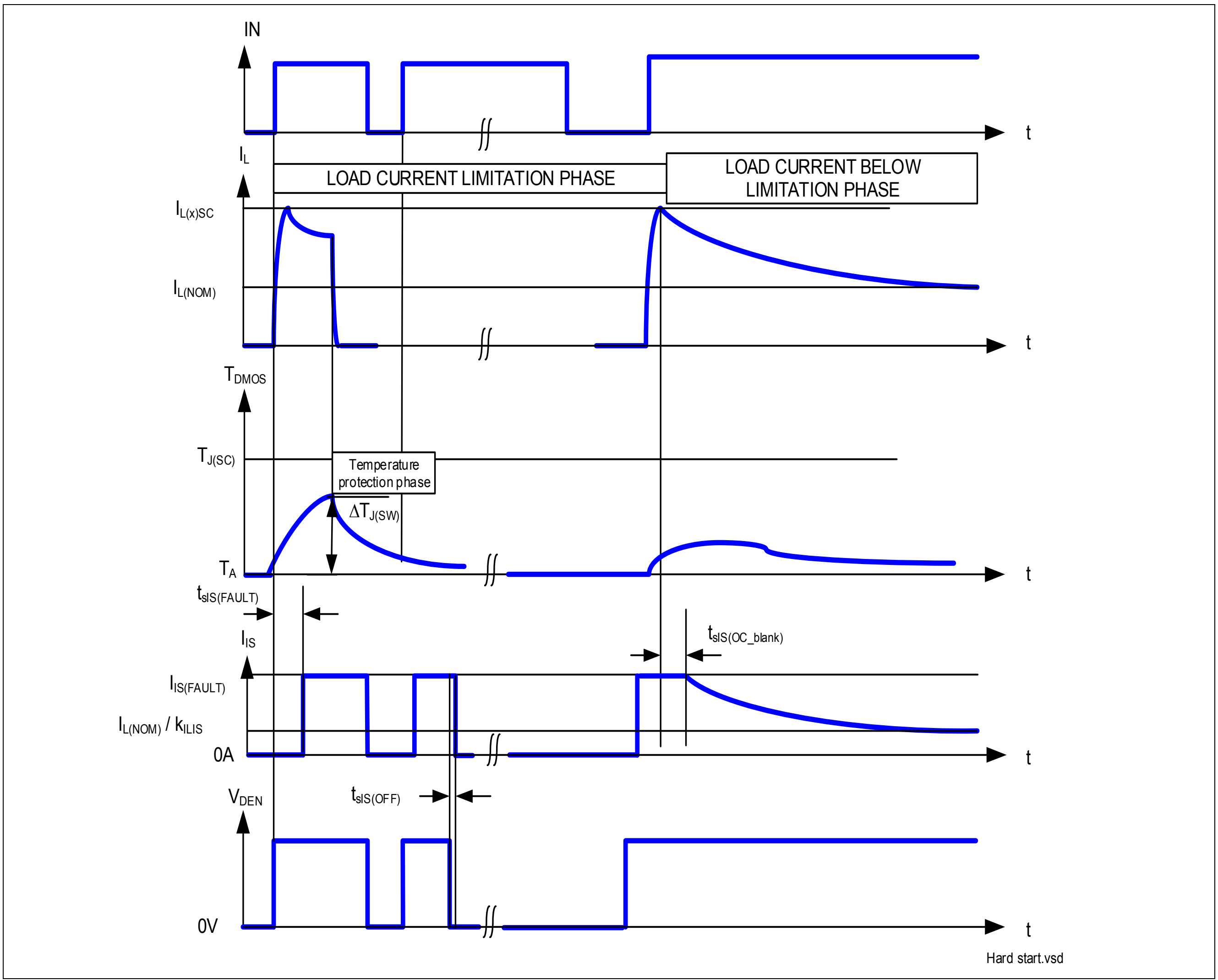


Figure 19 Overload Protection

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