PROFET™ +2 12V Smart High-Side Power Switch

Features

- High-Side Switch with Diagnosis and Embedded Protection
- Part of PROFET™ +2 12V Family
- Switching slew rate optimized for seat heating applications
- ReverseON for low power dissipation in Reverse Polarity
- Switch ON capability while Inverse Current condition (InverseON)
- Green Product (RoHS compliant)

AEC Qualified

RoHS

ISO 26262 ready

Potential applications

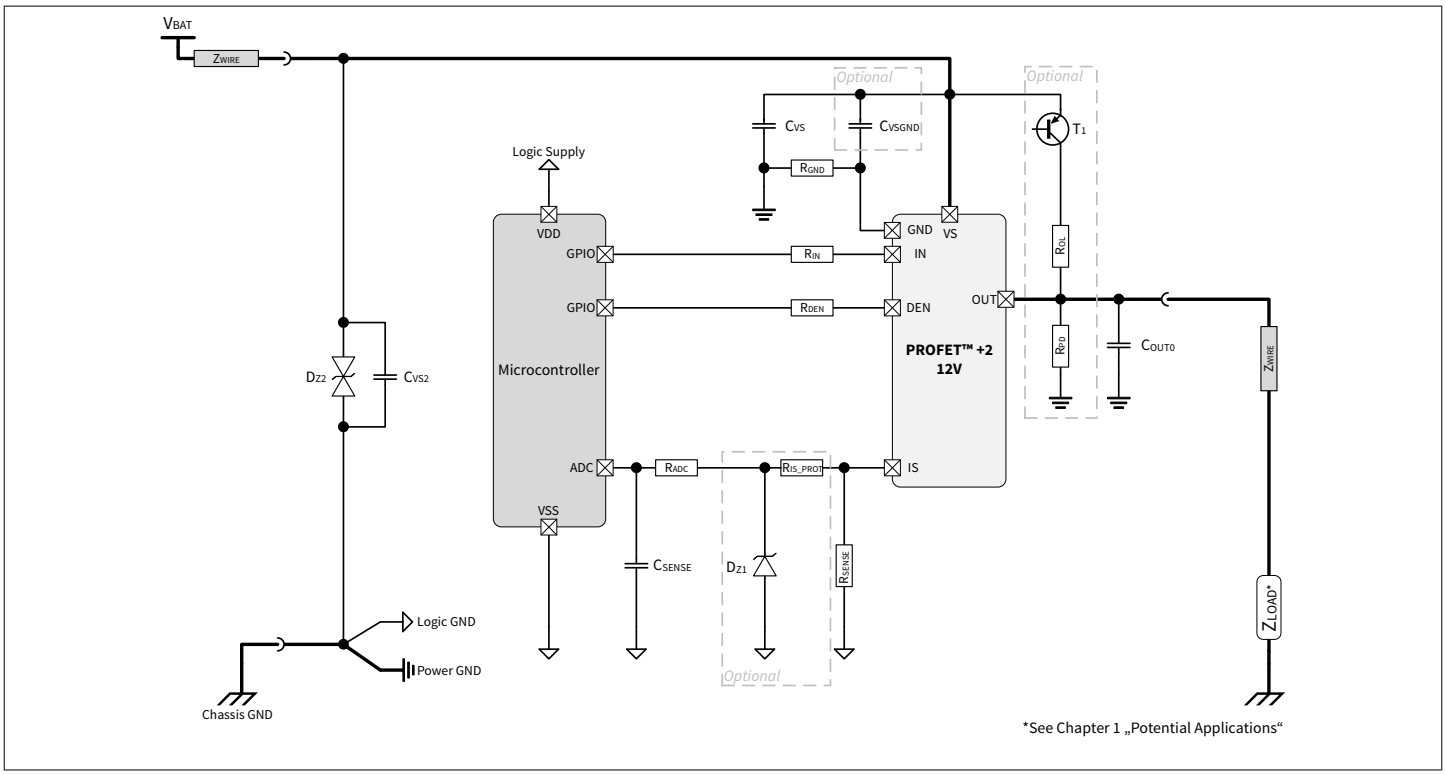
- Suitable for driving 15 A resistive, inductive and capacitive loads
- Replaces electromechanical relays, fuses and discrete circuits
- Suitable for power distribution applications and as main switch for ECU power supply
- Optimized for seat heating applications

Product validation

Qualified for automotive applications. Product validation according to AEC-Q100 Grade 1.

Description

The BTS7004-1EPR is a Smart High-Side Power Switch, providing protection functions and diagnosis.



Type	Package	Marking
BTS7004-1EPR	PG-TSDSO-14	7004-1R

Table of contents

1 Product Description

More functions are named in detail as follows:

Protection Features

- Absolute and dynamic temperature limitation with controlled reactivation
- Overcurrent protection (tripping) with Intelligent Latch
- Undervoltage shutdown
- Overvoltage protection with external components (as shown in Figure 35)

Diagnostic Features

- Proportional load current sense
- Open Load in ON and OFF state
- Short circuit to ground and battery

Table 1 Product Summary

Parameter	Symbol	Values
Minimum Operating voltage	$V_{S(OP)}$	4.1 V
Minimum Operating voltage (cranking)	$V_{S(UV)}$	3.1 V
Maximum Operating voltage	V_S	28 V
Minimum Overvoltage protection ($T_J \geq 25$ °C)	$V_{DS(CLAMP)\_25}$	35 V
Maximum current in OFF mode ($T_J \leq 85$ °C)	$I_{VS(OFF)\_85}$	0.5 µA
Maximum operative current	$I_{GND(ON\_D)}$	3 mA
Typical ON-state resistance ($T_J = 25$ °C)	$R_{DS(ON)\_25}$	4.4 mΩ
Maximum ON-state resistance ($T_J = 150$ °C)	$R_{DS(ON)\_150}$	8 mΩ
Nominal load current ($T_A = 85$ °C)	$I_{L(NOM)}$	15 A
Minimum overload detection current ($T_J = -40$°C)	$I_{L(OVL0)\_-40}$	87 A
Typical current sense ratio at $I_L = I_{L(NOM)}$	k_{ILIS}	17900

2 Block Diagram and Terms

2.1 Block Diagram

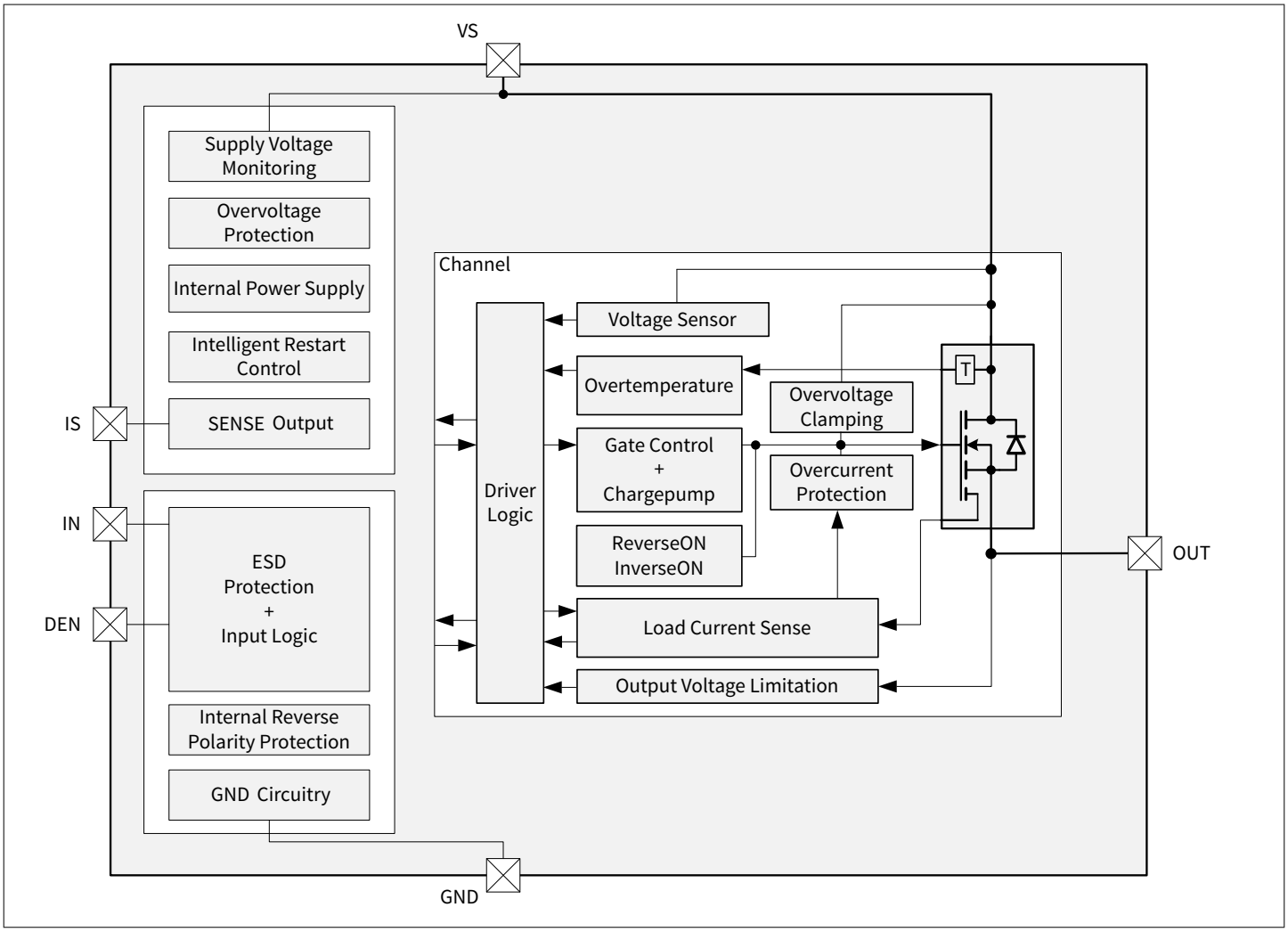


Figure 1 Block Diagram of BTS7004-1EPR

2.2 Terms

Figure 2 shows all terms used in this datasheet, with associated convention for positive values.

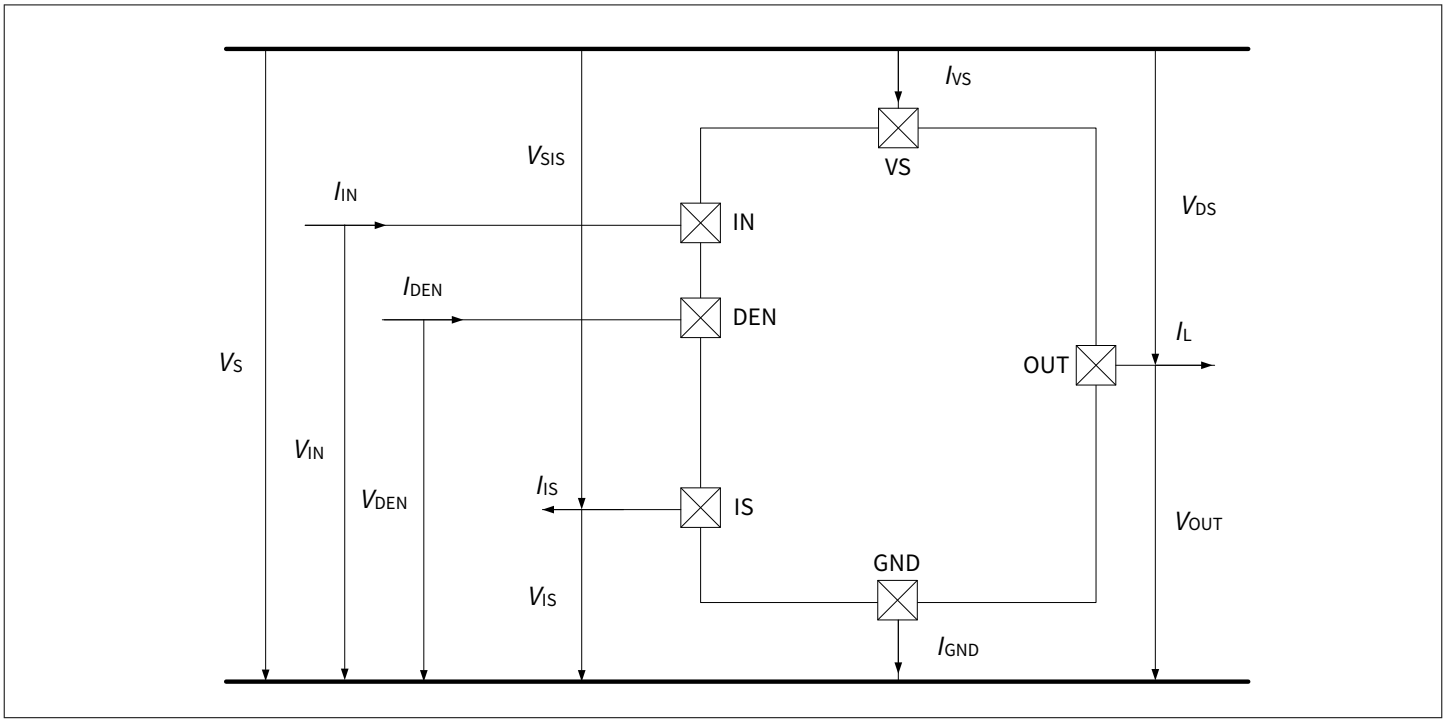


Figure 2 Voltage and Current Convention

3 Pin Configuration

3.1 Pin Assignment

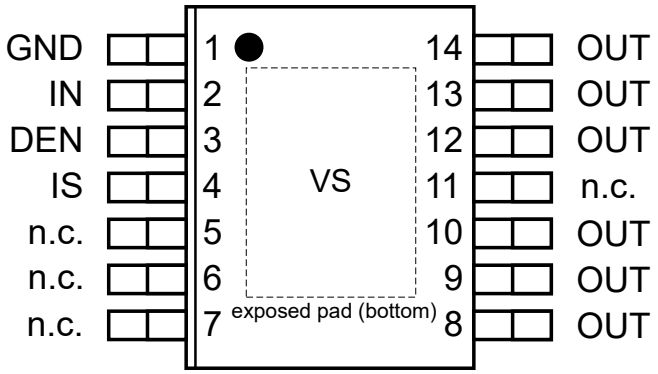


Figure 3 Pin Configuration

3.2 Pin Definitions and Functions

Table 2 Pin Definition

Pin	Symbol	Function
EP	VS (exposed pad)	**Supply Voltage** Battery voltage
1	GND	**Ground** Signal ground
2	IN	**Input Channel** Digital signal to switch ON the channel (“high” active) If not used: connect to GND pin or to module ground with resistor R_{IN} = 4.7 kΩ
3	DEN	**Diagnostic Enable** Digital signal to enable device diagnosis (“high” active) and to clear the protection latch of channel If not used: connect to GND pin or to module ground with resistor R_{DEN} = 4.7 kΩ
4	IS	**SENSE current output** Analog/digital signal for diagnosis If not used: left open
5-7, 11	n.c.	Not connected, internally not bonded
8-10, 12-14	OUT	**Output** Protected high-side power output channel [1)]

1) All output pins of the channel 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.

4 General Product Characteristics

4.1 Absolute Maximum Ratings - General

Table 3 Absolute Maximum Ratings[1)]

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

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Supply pins							
Power Supply Voltage	V_S	-0.3	–	28	V	–	P_4.1.0.1
Load Dump Voltage	$V_{BAT(LD)}$	–	–	35	V	suppressed Load Dump acc. to ISO16750-2 (2010). R_i = 2 Ω	P_4.1.0.3
Supply Voltage for Short Circuit Protection	$V_{BAT(SC)}$	0	–	24	V	Setup acc. to AEC-Q100-012	P_4.1.0.25
Reverse Polarity Voltage	$-V_{BAT(REV)}$	–	–	16	V	$t \leq 2$ min T_A = +25 °C Setup as described in Chapter 10	P_4.1.0.5
Current through GND Pin	I_{GND}	-50	–	50	mA	R_{GND} according to Chapter 10	P_4.1.0.9
Logic & control pins (Digital Input = DI) **DI = IN , DEN**							
Current through DI Pin	I_{DI}	-1	–	2	mA	2)	P_4.1.0.14
Current through DI Pin Reverse Battery Condition	$I_{DI(REV)}$	-1	–	10	mA	2) $t \leq 2$ min	P_4.1.0.36
IS pin							
Voltage at IS Pin	V_{IS}	-1.5	–	V_S	V	I_{IS} = 10 µA	P_4.1.0.16
Current through IS Pin	I_{IS}	-25	–	$I_{IS(SAT),MAX}$	mA	–	P_4.1.0.18
Temperatures							
Junction Temperature	T_J	-40	–	150	°C	–	P_4.1.0.19
Storage Temperature	T_{STG}	-55	–	150	°C	–	P_4.1.0.20
ESD Susceptibility							
ESD Susceptibility all Pins (HBM)	$V_{ESD(HBM)}$	-2	–	2	kV	HBM3)	P_4.1.0.21

(table continues...)

Table 3 (continued) Absolute Maximum Ratings[1)]

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

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
ESD Susceptibility OUT vs GND and VS connected (HBM)	$V_{ESD(HBM)\_OUT}$	-4	–	4	kV	HBM[3)]	P_4.1.0.22
ESD Susceptibility all Pins (CDM)	$V_{ESD(CDM)}$	-500	–	500	V	CDM[4)]	P_4.1.0.23
ESD Susceptibility Corner Pins (CDM) (pins 1, 7, 8, 14)	$V_{ESD(CDM)\_CRN}$	-750	–	750	V	CDM[4)]	P_4.1.0.24

1) Not subject to production test - specified by design.
2) Maximum V_{DI} to be considered for Latch-Up tests: 5.5 V.
3) ESD susceptibility, Human Body Model “HBM”, according to AEC Q100-002.
4) 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 datasheet. Fault conditions are considered as “outside” normal operating range. Protection functions are not designed for continuous repetitive operation.*

4.2 Absolute Maximum Ratings - Power Stages

4.2.1 Power Stage - 4 mΩ

Table 4 Absolute Maximum Ratings [1)]

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

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Maximum Energy Dissipation Single Pulse	E_{AS}	–	–	150	mJ	$I_L = 2*I_{L(NOM)}$ $T_{J(0)}$ = 150 °C V_S = 28 V	P_4.2.11.1
Maximum Energy Dissipation Repetitive Pulse	E_{AR}	–	–	44	mJ	$I_L = I_{L(NOM)}$ $T_{J(0)}$ = 85 °C V_S = 13.5 V 1M cycles	P_4.2.11.4
Load Current	$\|I_L\|$	–	–	$I_{L(OVL0),MAX}$	A	–	P_4.2.11.3

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

4.3 Functional Range

Table 5 Functional Range - Supply Voltage and Temperature [1)]

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Supply Voltage Range for Normal Operation	$V_{S(NOR)}$	6	13.5	18	V	–	P_4.3.0.1
Lower Extended Supply Voltage Range for Operation	$V_{S(EXT,LOW)}$	3.1	–	6	V	2) 3) (parameter deviations possible)	P_4.3.0.2
Supply Voltage Range reached after Overload Protection activation leading to “Undervoltage on V_S ” condition	$V_{S(EXT,CVG)}$	–	–	3.1	V	C_{VSGND} is required when the Overload Protection is triggered (see Chapter 8.2) and the observed number of retries is different from what specified in Chapter 8.3.1	P_4.3.0.7
Upper Extended Supply Voltage Range for Operation	$V_{S(EXT,UP)}$	18	–	28	V	3) (parameter deviations possible)	P_4.3.0.3
Junction Temperature	T_J	-40	–	150	°C	–	P_4.3.0.5

1) Not subject to production test - specified by design.
2) In case of V_S voltage decreasing: $V_{S(EXT,LOW),MIN}$ = 3.1 V. In case of V_S voltage increasing: $V_{S(EXT,LOW),MIN}$ = 4.1 V.

3) Protection functions still operative.

***Note**: Within the functional or operating range, the IC operates as described in the circuit description. The electrical characteristics are specified within the conditions given in the Electrical Characteristics tables.*

4.4 Thermal Resistance

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

Table 6 Thermal Resistance [1)]

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Thermal Characterization Parameter Junction-Top	Ψ_{JTOP}	–	3	5	K/W	2)	P_4.4.0.1
Thermal Resistance Junction-to-Case	R_{thJC}	–	1.4	2.4	K/W	2) simulated at exposed pad	P_4.4.0.2
Thermal Resistance Junction-to-Ambient	R_{thJA}	–	31.8	–	K/W	2)	P_4.4.0.3

1) Not subject to production test - specified by design.
2) According to Jedec JESD51-2,-5,-7 at natural convection on FR4 2s2p board; the Product (Chip + Package) was simulated on a 76.2 × 114.3 × 1.5 mm board with 2 inner copper layers (2 × 70 µm Cu, 2 × 35 µm Cu). Where applicable a thermal via array under the exposed pad contacted the first inner copper layer. Simulation done at T_A = 105°C, $P_{DISSIPATION}$ = 1 W.

4.4.1 PCB Setup

Figure 4 1s0p PCB Cross Section

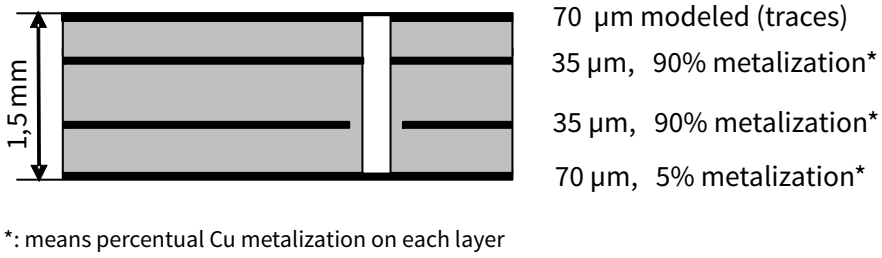


Figure 5 2s2p PCB Cross Section

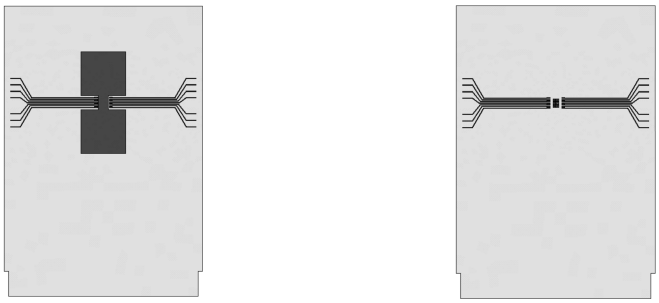


Figure 6 PCB setup for thermal simulations

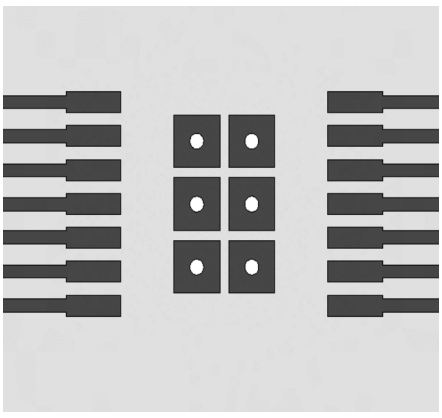


Figure 7 Thermal vias on PCB for 2s2p PCB setup

4.4.2 Thermal Impedance

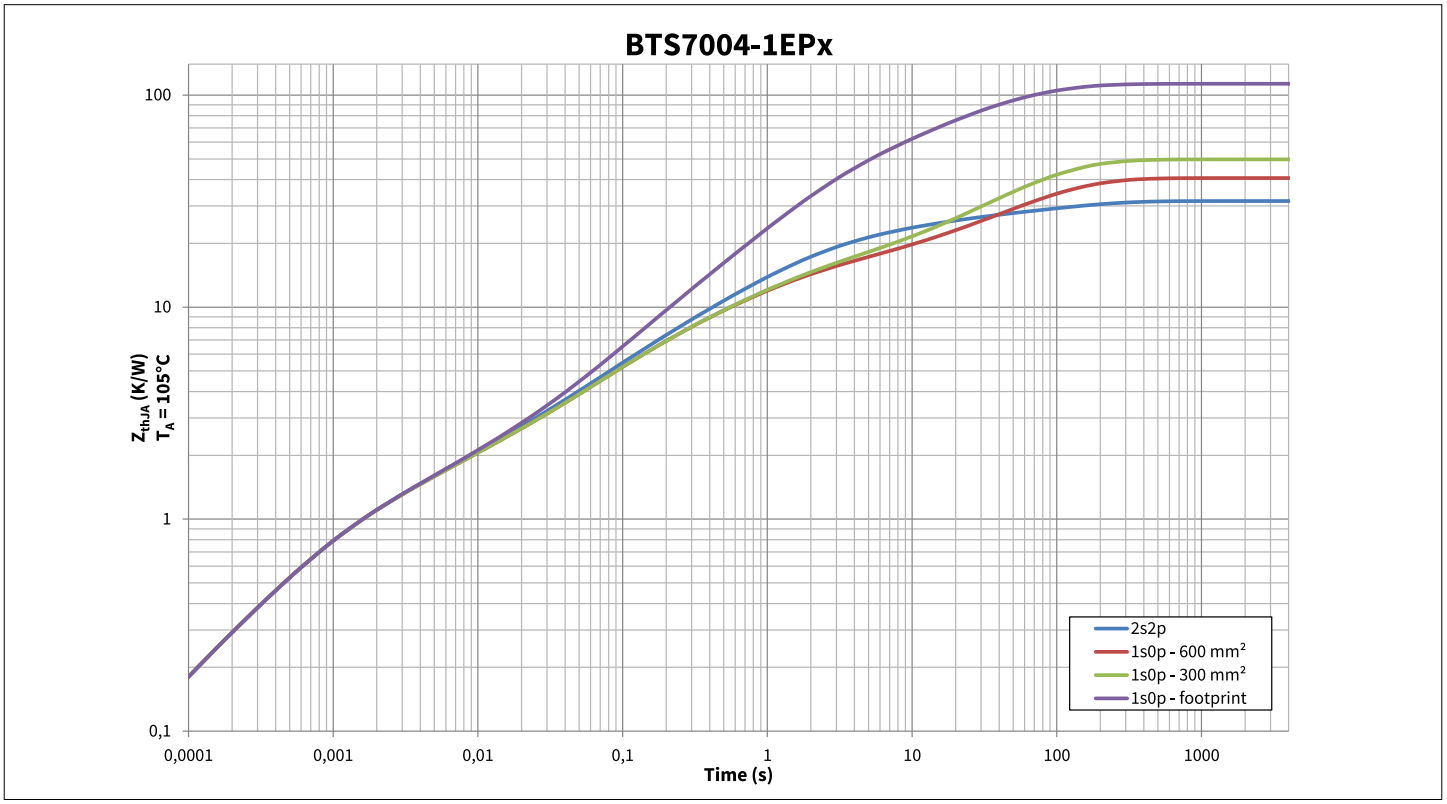


Figure 8 Typical Thermal Impedance. PCB setup according Chapter 4.4.1

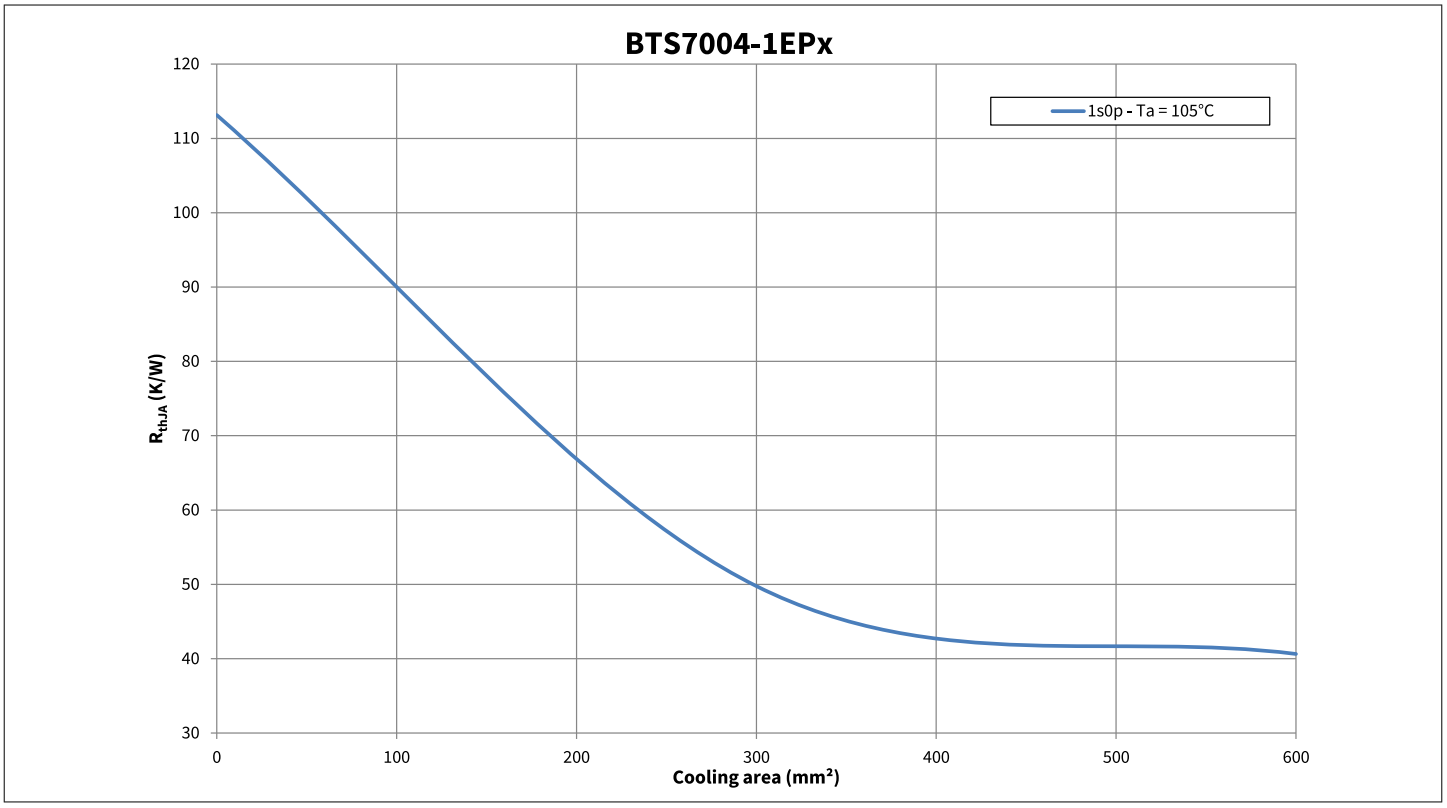


Figure 9 Thermal Resistance on 1s0p PCB with various cooling surfaces

5 Logic Pins

The device has 2 digital pins.

5.1 Input Pin (IN)

The input pin IN activates the output channel. The input circuitry is compatible with 3.3V and 5V microcontroller (see Chapter 10 for the complete application setup overview). The electrical equivalent of the input circuitry is shown in Figure 10. In case the pin is not used, it should be pulled to module GND or device GND pin via R_{IN} = 4.7 kΩ.

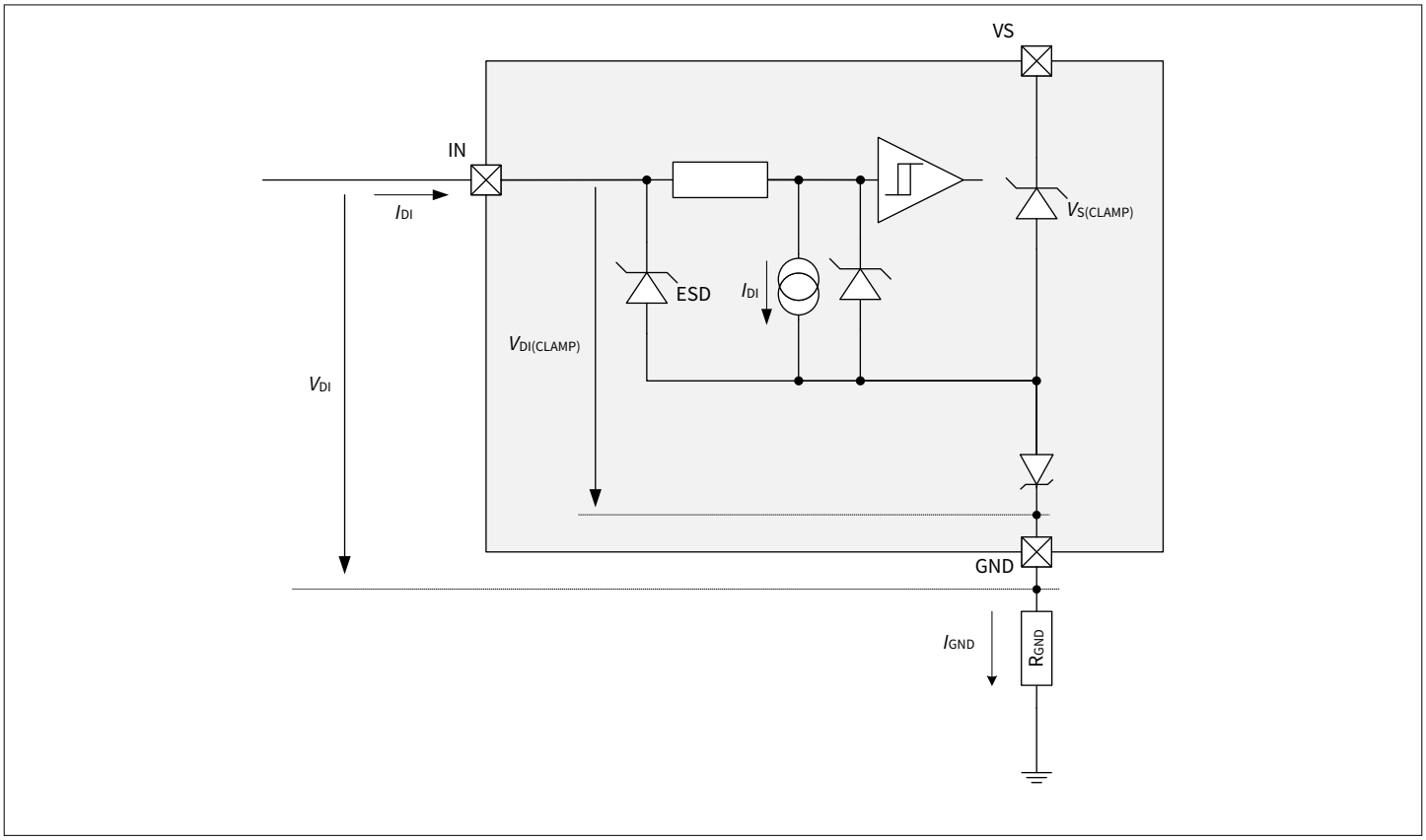


Figure 10 Input circuitry

The logic thresholds for “low” and “high” states are defined by parameters $V_{DI(TH)}$ and $V_{DI(HYS)}$. The relationship between these two values is shown in Figure 11. The voltage V_{IN} needed to ensure a “high” state is always higher than the voltage needed to ensure a “low” state.

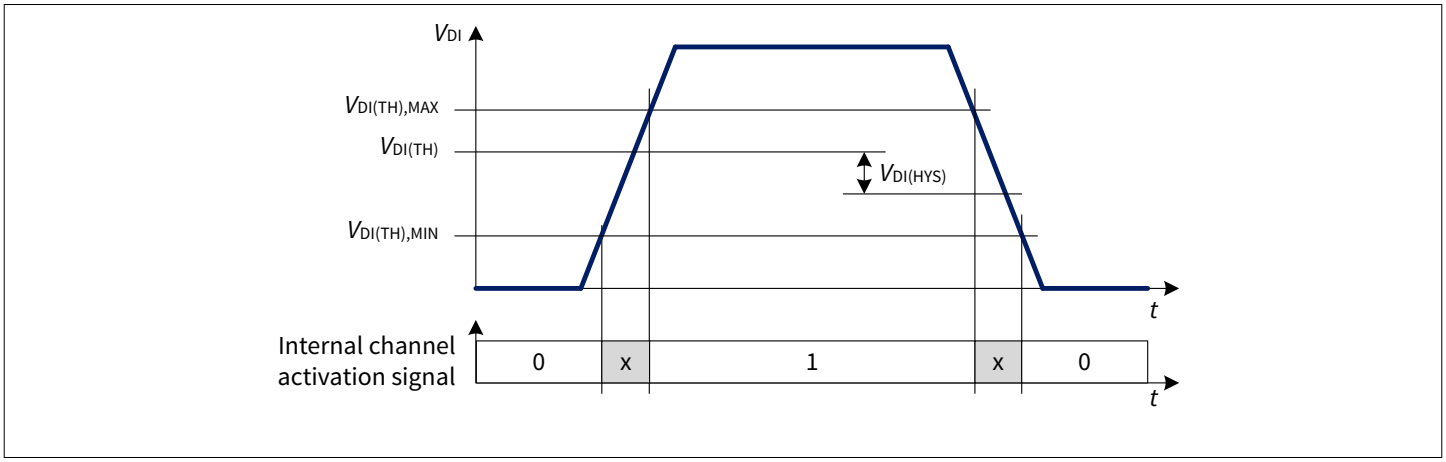


Figure 11 Input Threshold voltages and hysteresis

5.2 Diagnosis Pin

The Diagnosis Enable (DEN) pin controls the diagnosis circuitry and can be used to reset the latched protection (Protection circuitry not disabled by DEN). When DEN pin is set to “high”, the diagnosis is enabled (see Chapter 9.2 for more details). When it is set to “low”, the diagnosis is disabled (IS pin is set to high impedance).

The transition from “high” to “low” of DEN pin clears the protection latch of the channel depending on the logic state of IN pin and DEN pulse length (see Chapter 8.3 for more details). The internal structure of diagnosis pins is the same as the one of input pins. See Figure 10 for more details.

5.3 Electrical Characteristics Logic Pins

V_S = 6 V to 18 V, T_J = -40 °C to +150 °C

Typical values: V_S = 13.5 V, T_J = 25 °C

Digital Input (DI) pins = IN, DEN

Table 7 Electrical Characteristics: Logic Pins - General

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Digital Input Voltage Threshold	$V_{DI(TH)}$	0.8	1.3	2	V	See Figure 10 and Figure 11	P_5.4.0.1
Digital Input Clamping Voltage	$V_{DI(CLAMP1)}$	–	7	–	V	1) I_{DI} = 1 mA See Figure 10 and Figure 11	P_5.4.0.2
Digital Input Clamping Voltage	$V_{DI(CLAMP2)}$	6.5	7.5	8.5	V	I_{DI} = 2 mA See Figure 10 and Figure 11	P_5.4.0.3
Digital Input Hysteresis	$V_{DI(HYS)}$	–	0.25	–	V	1) See Figure 10 and Figure 11	P_5.4.0.4
Digital Input Current (“high”)	$I_{DI(H)}$	2	10	25	µA	V_{DI} = 2 V See Figure 10 and Figure 11	P_5.4.0.5
Digital Input Current (“low”)	$I_{DI(L)}$	2	10	25	µA	V_{DI} = 0.8 V See Figure 10 and Figure 11	P_5.4.0.6

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

6 Power Supply

The BTS7004-1EPR is supplied by V_S , which is used for the internal logic as well as supply for the power output stage. V_S has an undervoltage detection circuit, which prevents the activation of the power output stage and diagnosis in case the applied voltage is below the undervoltage threshold ($V_S < V_{S(OP)}$). During power up, the internal power on signal is set when supply voltage (V_S) exceeds the minimum operating voltage ($V_S > V_{S(OP)}$).

6.1 Operation Modes

BTS7004-1EPR has the following operation modes in case of $V_S > V_{S(OP)}$:

- OFF mode
- ON mode
- Diagnosis in ON mode
- Diagnosis in OFF mode
- Fault

The transition between operation modes is determined according to these variables:

- Logic level at IN pin
- Logic level at DEN pin
- Internal latch

The truth table in case of $V_S > V_{S(OP)}$ is shown in Table 8. The behavior of BTS7004-1EPR as well as some parameters may change in dependence on the operation mode of the device.

There are three parameters describing each operation mode of BTS7004-1EPR:

- Status of the output channel
- Status of the diagnosis
- Current consumption at VS pin (measured by I_{VS} in OFF mode, I_{GND} in all other operative modes)

Table 8 Operation Mode truth table

IN	DEN	Internal latch	I_{IS}	Operative Mode	Comment
0	0	0	leakage	OFF	DMOS channel is OFF
0	0	1	leakage	OFF	DMOS channel is OFF
0	1	0	leakage	OFF_DIAG	Diagnostic in OFF-mode
			open load		Diagnostic in OFF-mode
0	1	1	fault		Diagnostic in OFF-mode
1	0	0	leakage	ON	DMOS channel is ON, no diagnostic
1	0	1	leakage	fault	DMOS channel is switched OFF due to failure
1	1	0	I_{IS}	ON_DIAG	DMOS channel is ON and diagnostic
1	1	1	fault	fault	DMOS channel is switched OFF due to failure

6.1.1 OFF mode

When BTS7004-1EPR is in OFF mode, the output channel is OFF. The current consumption is minimum (see parameter $I_{VS(OFF)}$). No Overtemperature, Overload protection mechanism and no diagnosis function is active when the device is in OFF mode.

6.1.2 ON mode

ON (IN = High; DEN = Low) mode is the normal operation mode of BTS7004-1EPR. Device current consumption is specified with $I_{GND(ON\_D)} + I_{IS(OFF)}$ (measured at GND pin because the current at VS pin includes the load current). Overcurrent and Overtemperature protections are active. No diagnosis function is active.

6.1.3 OFF_Diag mode

The device is in OFF_Diag mode as long as DEN pin is set to “high” and IN pin is set to “low”. The output channel is OFF. Depending on the load condition, either a fault current $I_{IS(FAULT)}$ or an Open Load in OFF current ($I_{IS(OLOFF)}$) may be present at IS pin. In such situation, the current consumption of the device is increased.

6.1.4 ON_Diag mode

The device is in ON_Diag mode with current sense function enabled. Device current consumption is specified with $I_{GND(ON\_D)}$. Depending on the load condition, either a fault current $I_{IS(FAULT)}$ or I_{IS} current may be present at IS pin.

6.1.5 Fault mode

The device is in Fault mode as soon as a protection event happens which affects that the device switches off due to its protection function. In Fault mode, a $I_{IS(FAULT)}$ signal is present at IS pin during the DEN signal is "high".

6.2 Undervoltage on V_S

Between $V_{S(OP)}$ and $V_{S(UV)}$ the undervoltage mechanism is triggered. If the device is operative (in ON mode) and the supply voltage drops below the undervoltage threshold $V_{S(UV)}$, the internal logic switches OFF the output channel.

As soon as the supply voltage V_S is above the operative threshold $V_{S(OP)}$, the channel is switched ON again as shown in Figure 12.

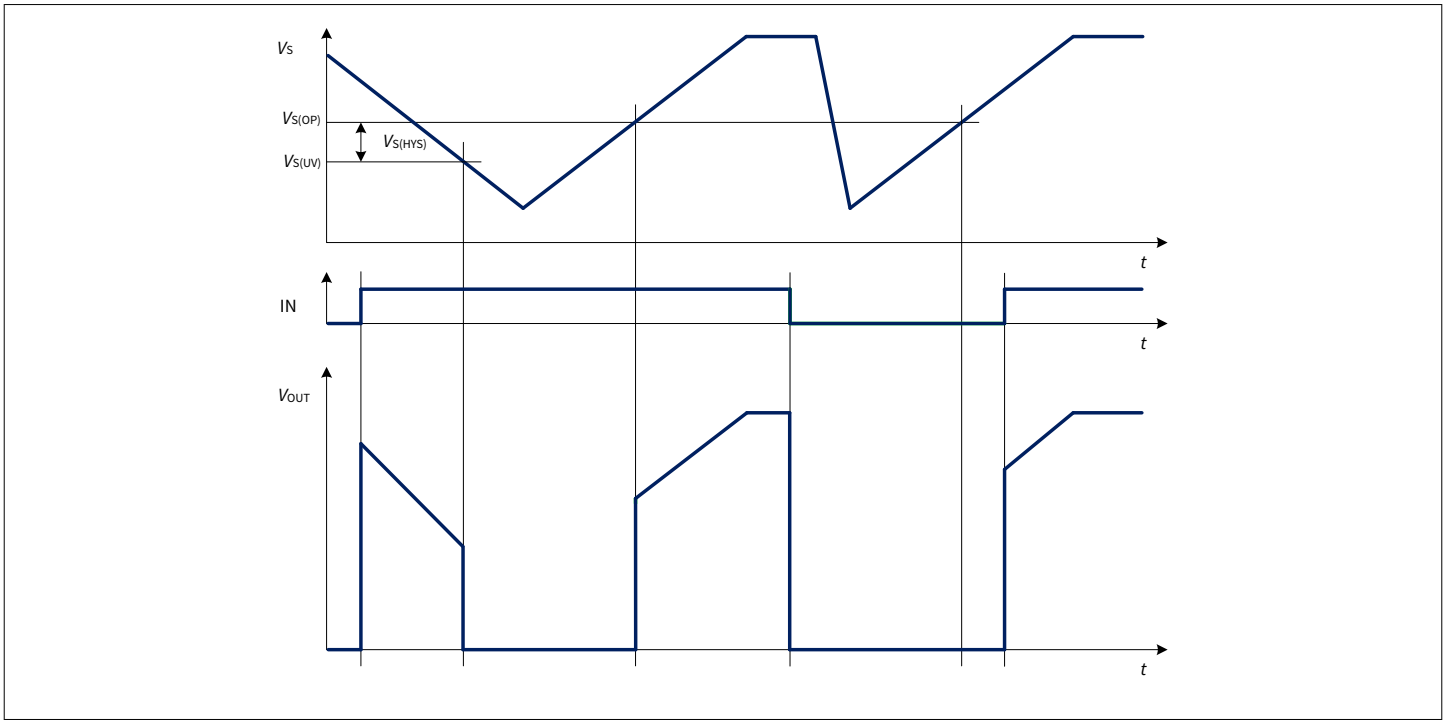


Figure 12 V_S undervoltage behavior

6.3 Electrical Characteristics Power Supply

V_S = 6 V to 18 V, T_J = -40 °C to +150 °C
Typical values: V_S = 13.5 V, T_J = 25 °C
Typical resistive load connected to the output for testing (unless otherwise specified):
R_L = 4 Ω

Table 9 Electrical Characteristics: Power Supply - General

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
VS pin							
Power Supply Undervoltage Shutdown	$V_{S(UV)}$	1.8	2.3	3.1	V	V_S decreasing IN = “high” From $V_{DS} \le 0.5$ V to $V_{DS} = V_S$ See Figure 12	P_6.4.0.1
Power Supply Minimum Operating Voltage	$V_{S(OP)}$	2.0	3.0	4.1	V	V_S increasing IN = “high” From $V_{DS} = V_S$ to $V_{DS} \le 0.5$ V See Figure 12	P_6.4.0.3
Power Supply Undervoltage Shutdown Hysteresis	$V_{S(HYS)}$	–	0.7	–	V	1) $V_{S(OP)} - V_{S(UV)}$ See Figure 12	P_6.4.0.6
Breakdown Voltage between GND and VS Pins in Reverse Battery	$-V_{S(REV)}$	16	–	30	V	1) $I_{GND(REV)}$ = 7 mA T_J = 150 °C	P_6.4.0.9

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

6.4 Electrical Characteristics Power Supply - Product Specific

V_S = 6 V to 18 V, T_J = -40 °C to +150 °C
Typical values: V_S = 13.5 V, T_J = 25 °C
Typical resistive load connected to the output for testing (unless otherwise specified):
R_L = 4 Ω

6.4.1 BTS7004-1EPR

Table 10 Electrical Characteristics: Power Supply BTS7004-1EPR

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Supply Current Consumption in OFF Mode with Loads	$I_{VS(OFF)\_85}$	–	0.05	0.5	µA	1) V_S = 18 V V_{OUT} = 0 V IN = DEN = “low” $T_J \leq$ 85 °C	P_6.5.21.1
Supply Current Consumption in OFF Mode with Loads	$I_{VS(OFF)\_150}$	–	5	20	µA	V_S = 18 V V_{OUT} = 0 V IN = DEN = “low” T_J = 150 °C	P_6.5.21.2
Operating Current in ON_Diag Mode (Channel ON)	$I_{GND(ON\_D)}$	–	2	3	mA	V_S = 18 V IN = DEN = “high”	P_6.5.21.3
Operating Current in OFF_Diag Mode	$I_{GND(OFF\_D)}$	–	1.2	1.8	mA	V_S = 18 V IN = “low”; DEN = “high”	P_6.5.21.5

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

7 Power Stages

The high-side power stage is built using a N-channel vertical Power MOSFET with charge pump.

7.1 Output ON-State Resistance

The ON-state resistance $R_{DS(ON)}$ depends mainly on junction temperature T_J. Figure 13 shows the variation of $R_{DS(ON)}$ across the whole T_J range. The value “2” on the y-axis corresponds to the maximum $R_{DS(ON)}$ measured at T_J = 150 °C.

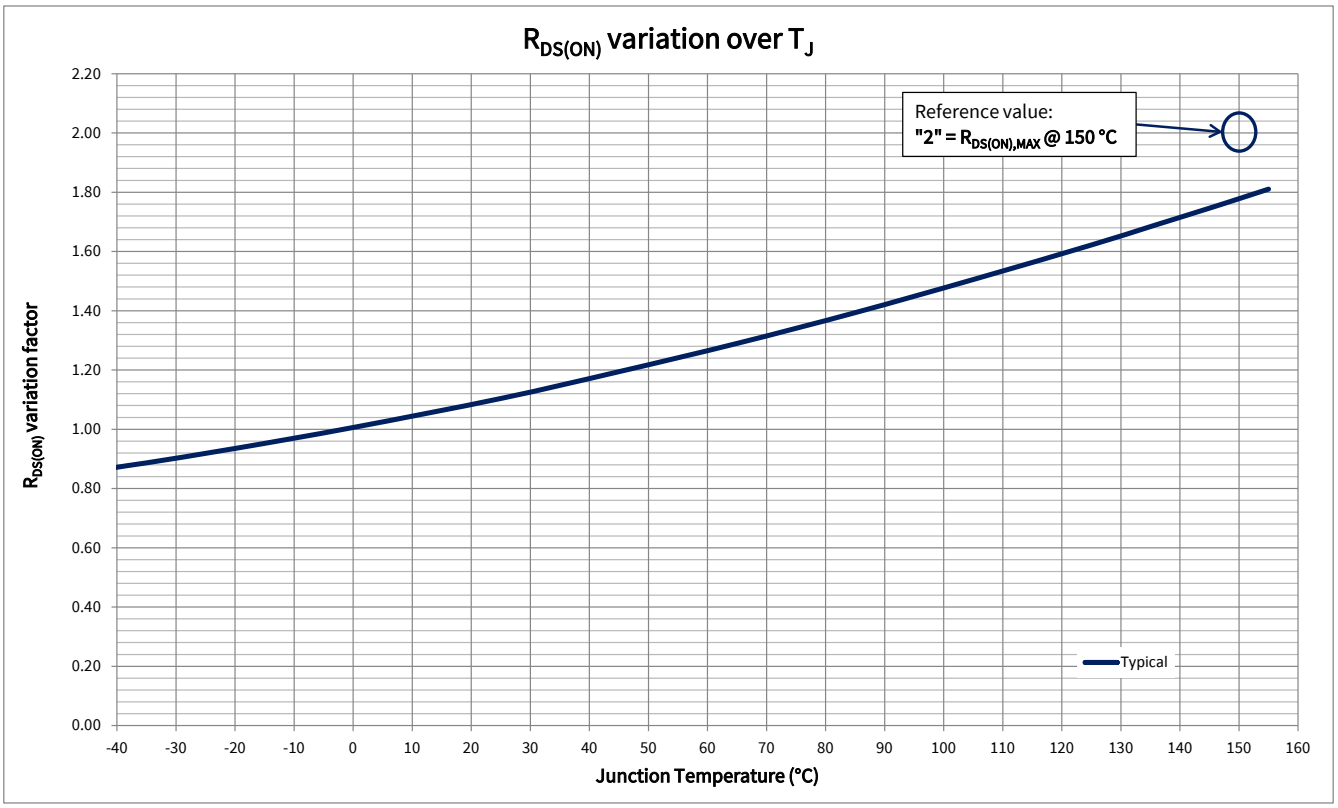


Figure 13 $R_{DS(ON)}$ variation factor

The behavior in Reverse Polarity is described in Chapter 8.4.1.

7.2 Switching loads

7.2.1 Switching Resistive Loads

When switching resistive loads, the switching times and slew rates shown in Figure 14 can be considered. The switch energy values E_{ON} and E_{OFF} are proportional to load resistance and times t_{ON} and t_{OFF}.

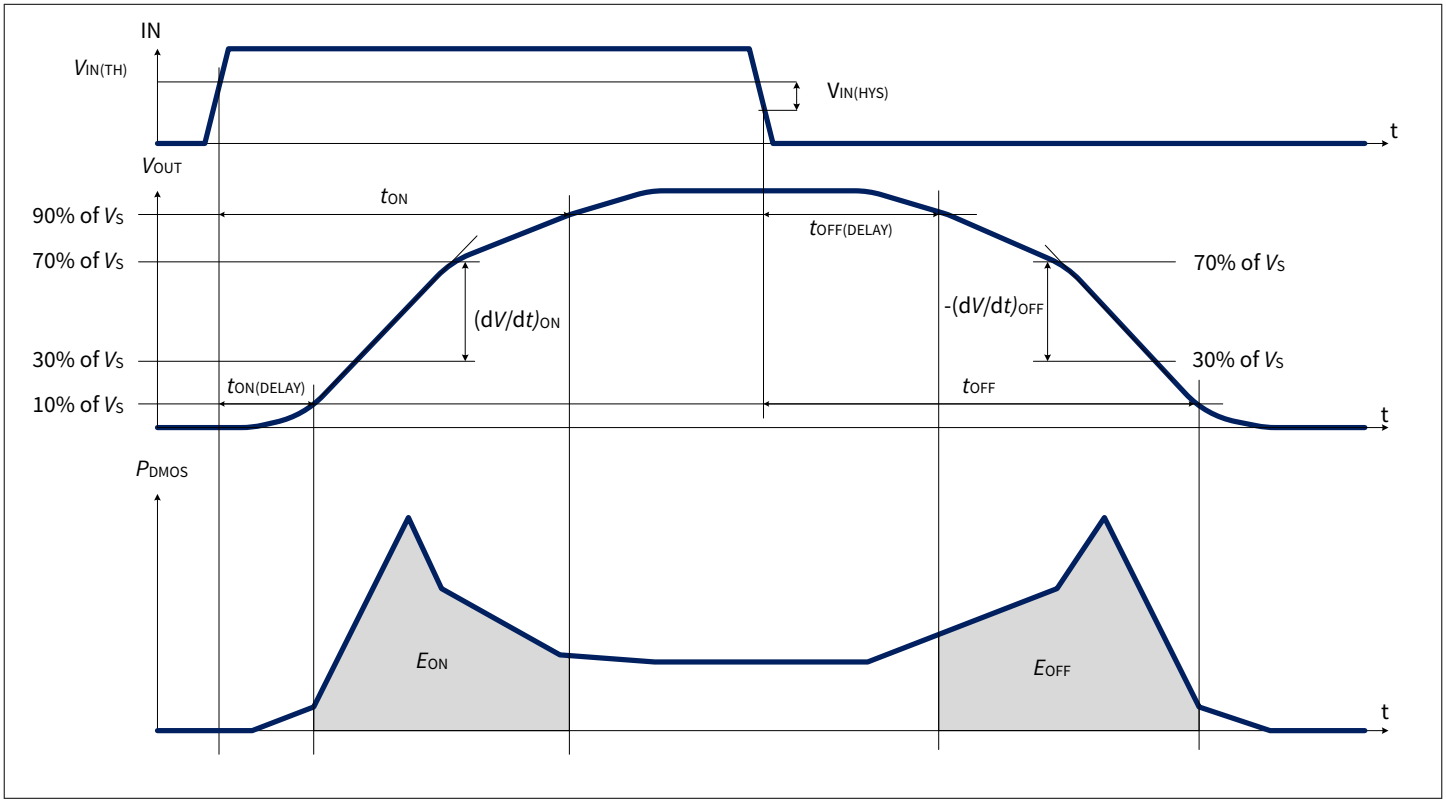


Figure 14 Switching a Resistive Load

7.2.2 Switching Inductive Loads

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 due to overvoltage, a voltage clamp mechanism is implemented. The clamping structure limits the negative output voltage so that V_{DS} = $V_{DS(CLAMP)}$. Figure 15 shows a concept drawing of the implementation. The clamping structure is available in all operation modes listed in Chapter 6.1.

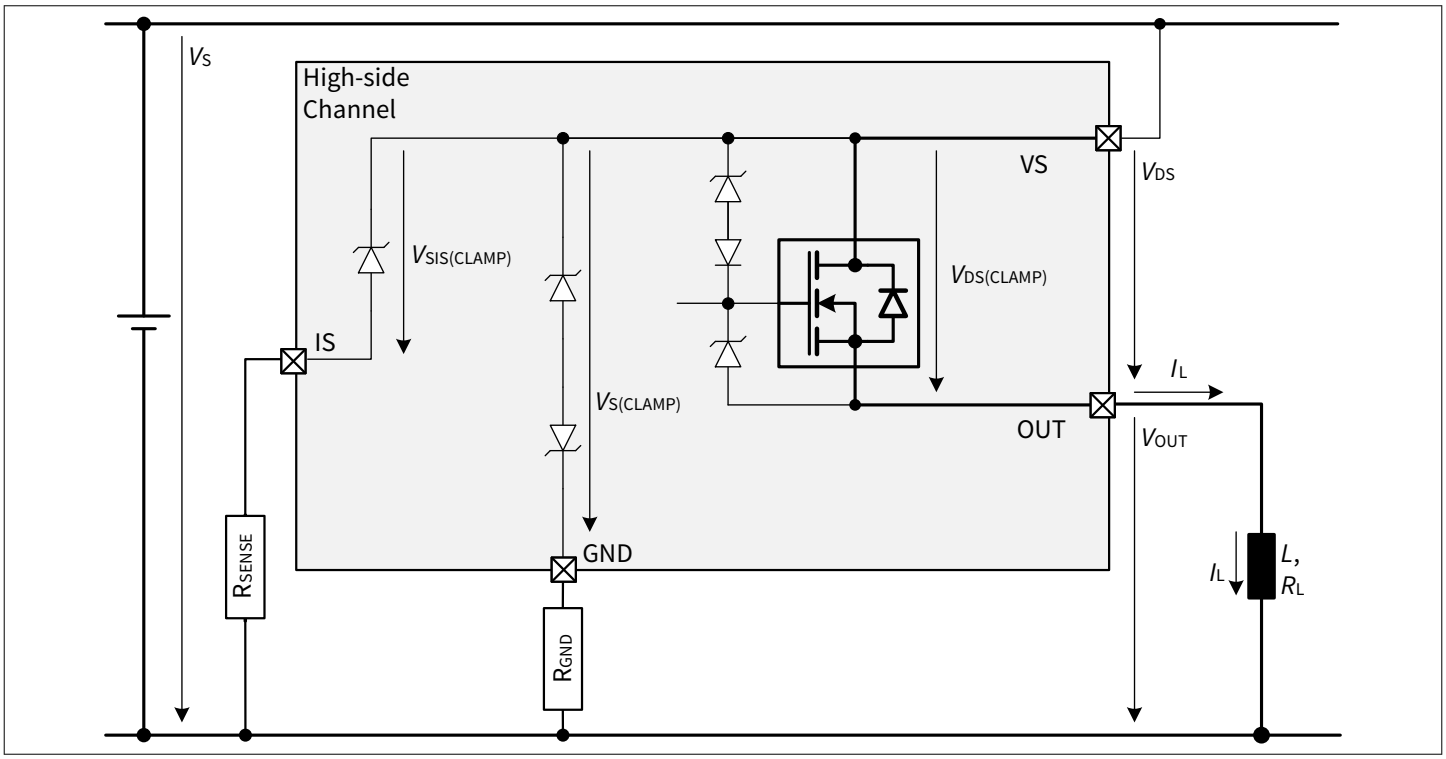


Figure 15 Output Clamp concept

During demagnetization of inductive loads, energy has to be dissipated in BTS7004-1EPR. The energy can be calculated with (1):

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

The maximum energy, therefore the maximum inductance for a given current, is limited by the thermal design of the component. Please refer to Chapter 4.2 for the maximum allowed values of E_{AS} (single pulse energy) and E_{AR} (repetitive energy).

7.2.3 Output Voltage Limitation

To increase the current sense accuracy, V_{DS} voltage is monitored. When the output current I_L decreases while the channel is diagnosed (DEN pin set to “high” - see Figure 16) bringing V_{DS} equal or lower than $V_{DS(SLC)}$, the output DMOS gate is partially discharged. This increases the output resistance so that $V_{DS} = V_{DS(SLC)}$ even for very small output currents. The V_{DS} increase allows the current sensing circuitry to work more efficiently, providing better k_{ILIS} accuracy for output current in the low range.

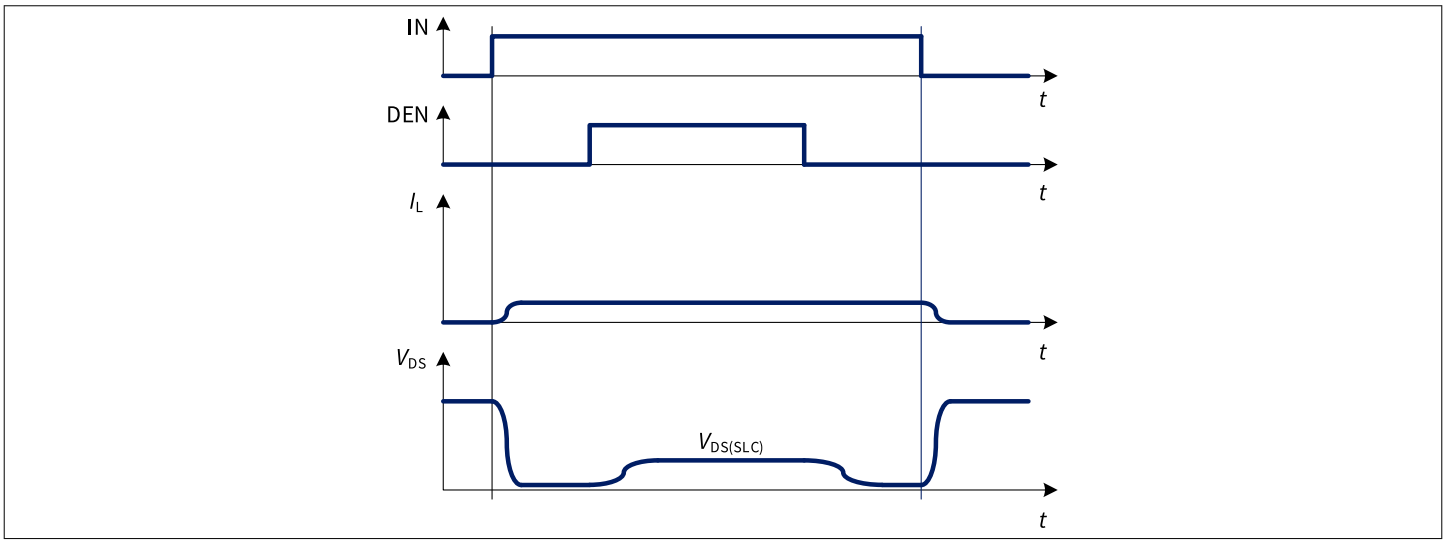


Figure 16 Output Voltage Limitation activation during diagnosis

7.3 Advanced Switching Characteristics

7.3.1 Inverse Current behavior

When $V_{OUT} > V_S$, a current I_{INV} flows into the power output transistor (see Figure 17). This condition is known as “Inverse Current”.

If the channel is in OFF state, the current flows through the intrinsic body diode generating high power losses therefore an increase of overall device temperature. If the channel is in ON state, $R_{DS(INV)}$ can be expected and power dissipation in the output stage is comparable to normal operation in $R_{DS(ON)}$.

During Inverse Current condition, the channel remains in ON or OFF state as long as $|I_L| < |I_{L(INV)}|$.

With InverseON, it is possible to switch ON the channel during Inverse Current condition as long as $|I_L| < |I_{L(INV)}|$ (see Figure 18).

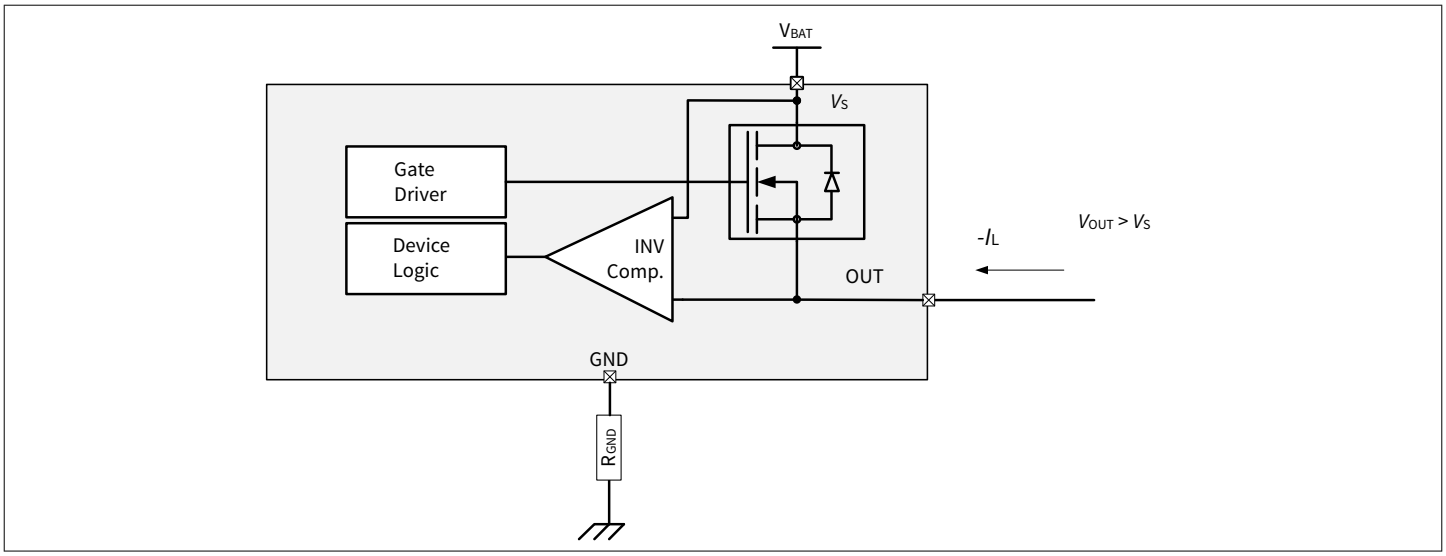


Figure 17 Inverse Current Circuitry

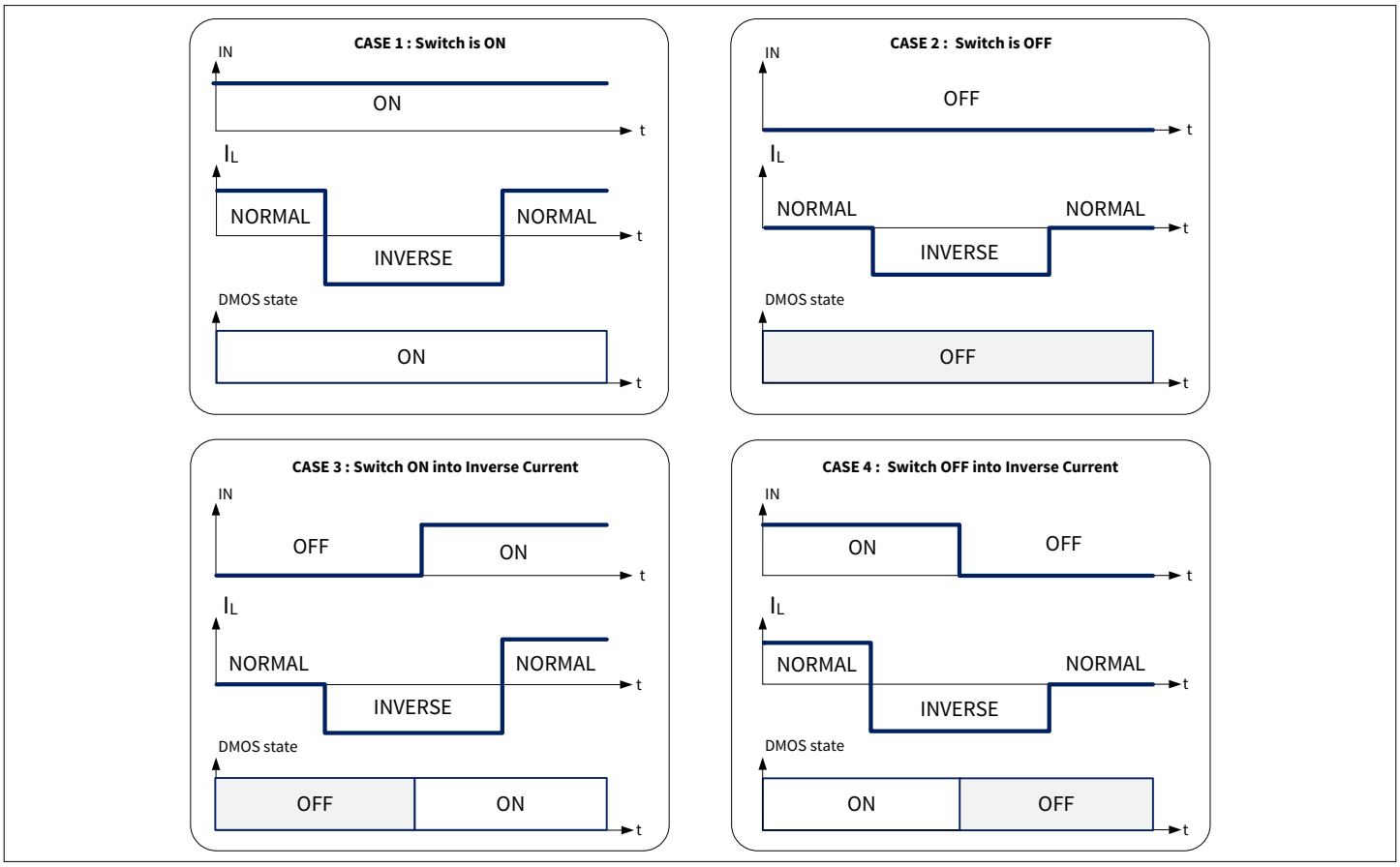


Figure 18 InverseON - Channel behavior in case of applied Inverse Current

***Note**: No protection mechanism like Overtemperature or Overload protection is active during applied Inverse Currents.*

7.4 Electrical Characteristics Power Stages

V_S = 6 V to 18 V, T_J = -40 °C to +150 °C
Typical values: V_S = 13.5 V, T_J = 25 °C
Typical resistive load connected to the output for testing (unless otherwise specified):
R_L = 4 Ω

Table 11 Electrical Characteristics: Power Stages - General

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Voltages							
Drain to Source Clamping Voltage at T_J = -40 °C	$V_{DS(CLAMP)\_-40}$	33	36.5	42	V	I_L = 5 mA T_J = -40°C See Figure 15	P_7.4.0.1
Drain to Source Clamping Voltage at $T_J \geq$ 25 °C	$V_{DS(CLAMP)\_25}$	35	38	44	V	1) I_L = 5 mA $T_J \geq$ 25°C See Figure 15	P_7.4.0.2

1) Tested at T_J = 150°C.

7.4.1 Electrical Characteristics Power Stages

Table 12 Electrical Characteristics Power Stages

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Timings							
Switch-ON Delay	$t_{ON(DELAY)}$	300	750	1200	µs	V_S = 13.5 V V_{OUT} = 10% V_S See Figure 14	P_7.4.6.1
Switch-OFF Delay	$t_{OFF(DELAY)}$	40	120	200	µs	V_S = 13.5 V V_{OUT} = 90% V_S See Figure 14	P_7.4.6.2
Switch-ON Time	t_{ON}	650	1225	1800	µs	V_S = 13.5 V V_{OUT} = 90% V_S See Figure 14	P_7.4.6.3
Switch-OFF Time	t_{OFF}	300	550	800	µs	V_S = 13.5 V V_{OUT} = 10% V_S See Figure 14	P_7.4.6.4
Switch-ON/OFF Matching t_{ON} - t_{OFF}	Δt_{SW}	200	650	1000	µs	V_S = 13.5 V	P_7.4.6.5

(table continues...)

Table 12 (continued) Electrical Characteristics Power Stages

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Voltage Slope							
Switch-ON Slew Rate	$(dV/dt)_{ON}$	0.016	0.027	0.039	V/µs	V_S = 13.5 V V_{OUT} = 30% to 70% of V_S See Figure 14	P_7.4.6.6
Switch-OFF Slew Rate	$-(dV/dt)_{OFF}$	0.016	0.027	0.039	V/µs	V_S = 13.5 V V_{OUT} = 70% to 30% of V_S See Figure 14	P_7.4.6.7
Slew Rate Matching $(dV/dt)_{ON}$ - $(dV/dt)_{OFF}$	$\Delta(dV/dt)_{SW}$	-0.03	0	0.03	V/µs	V_S = 13.5 V	P_7.4.6.8
Voltages							
Output Voltage Drop Limitation at Small Load Currents	$V_{DS(SLC)}$	2	10	20	mV	1) I_{OUT} = $I_{OUT(OL)}$ = 20 mA	P_7.4.6.9

1) Not subject to production test - specified by design

7.5 Electrical Characteristics - Power Output Stages

V_S = 6 V to 18 V, T_J = -40 °C to +150 °C
Typical values: V_S = 13.5 V, T_J = 25 °C
Typical resistive load connected to the output for testing (unless otherwise specified):
R_L = 4 Ω

7.5.1 Power Output Stage - 4 mΩ

Table 13 Electrical Characteristics: Power Stages - 4 mΩ

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Output characteristics							
ON-State Resistance at T_J = 25 °C	$R_{DS(ON)\_25}$	–	4.4	–	mΩ	1) T_J = 25 °C	P_7.5.11.1
ON-State Resistance at T_J = 150 °C	$R_{DS(ON)\_150}$	–	–	8	mΩ	T_J = 150 °C	P_7.5.11.2
ON-State Resistance in Cranking	$R_{DS(ON)\_CRANK}$	–	–	10	mΩ	T_J = 150 °C V_S = 3.1 V	P_7.5.11.3

(table continues...)

Table 13 (continued) Electrical Characteristics: Power Stages - 4 mΩ

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
ON-State Resistance in Inverse Current at T_J = 25 °C	$R_{DS(INV)\_25}$	–	4.5	–	mΩ	1) T_J = 25 °C V_S = 13.5 V I_L = -4 A DEN = “low” see Figure 17	P_7.5.11.4
ON-State Resistance in Inverse Current at T_J = 150 °C	$R_{DS(INV)\_150}$	–	–	10	mΩ	T_J = 150 °C V_S = 13.5 V I_L = -4 A DEN = “low” see Figure 17	P_7.5.11.5
ON-State Resistance in Reverse Polarity at T_J = 25 °C	$R_{DS(REV)\_25}$	–	9.5	–	mΩ	1) T_J = 25 °C V_S = -13.5 V I_L = -4 A see Figure 27	P_7.5.11.6
ON-State Resistance in Reverse Polarity at T_J = 150 °C	$R_{DS(REV)\_150}$	–	–	16	mΩ	T_J = 150 °C V_S = -13.5 V I_L = -4 A	P_7.5.11.7
Nominal Load Current	$I_{L(NOM)}$	–	15	–	A	1) T_A = 85 °C $T_J \leq$ 150 °C	P_7.5.11.8
Output Leakage Current at $T_J \leq$ 85 °C	$I_{L(OFF)\_85}$	–	0.05	0.5	µA	1) V_{OUT} = 0 V V_{IN} = “low” $T_A \leq$ 85 °C	P_7.5.11.9
Output Leakage Current at T_J = 150 °C	$I_{L(OFF)\_150}$	–	–	15	µA	V_{OUT} = 0 V V_{IN} = “low” T_A = 150 °C	P_7.5.11.10
Inverse Current Capability	$I_{L(INV)}$	–	-15	–	A	1) $V_S < V_{OUT}$ IN = “high” see Figure 17	P_7.5.11.11
Voltage Slope							
Passive Slew Rate	$\lvert dV_{OUT} / dt \rvert$	–	–	10	V/µs	1) V_S = 13.5 V	P_7.5.11.12

(table continues...)

Table 13 (continued) Electrical Characteristics: Power Stages - 4 mΩ

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Voltages							
Drain Source Diode Voltage	$\lvert V_{DS(DIODE)} \rvert$	–	550	700	mV	I_L = -190 mA T_J = 150 °C	P_7.5.11.13
Switching Energy							
Switch-ON Energy	E_{ON}	–	13.5	–	mJ	V_S = 18 V see Figure 14 R_L = 2.1 Ohm	P_7.5.11.23
Switch-OFF Energy	E_{OFF}	–	15	–	mJ	V_S = 18 V see Figure 14 R_L = 2.1 Ohm	P_7.5.11.24

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

8 Protection

The BTS7004-1EPR is protected against Overtemperature, Overload, Reverse Battery (with ReverseON) and Overvoltage. Overtemperature and Overload protections are working when the device is in ON or ON_Diag mode but not during InverseON and ReverseON function. Overvoltage protection works in all operation modes. Reverse Battery protection works when the GND and VS pins are reverse supplied.

8.1 Overtemperature Protection

The device incorporates both an absolute ($T_{J(ABS)}$) and a dynamic ($T_{J(DYN)}$) temperature protection circuitry for the channel. An increase of junction temperature T_J above either one of the two thresholds ($T_{J(ABS)}$ or $T_{J(DYN)}$) switches OFF the overheated channel to prevent destruction. The channel remains switched OFF until junction temperature has reached the “Reactivation” condition described in Table 14. The behavior is shown in Figure 19 (absolute Overtemperature Protection) and Figure 20 (dynamic Overtemperature Protection). $T_{J(REF)}$ is the reference temperature used for dynamic temperature protection.

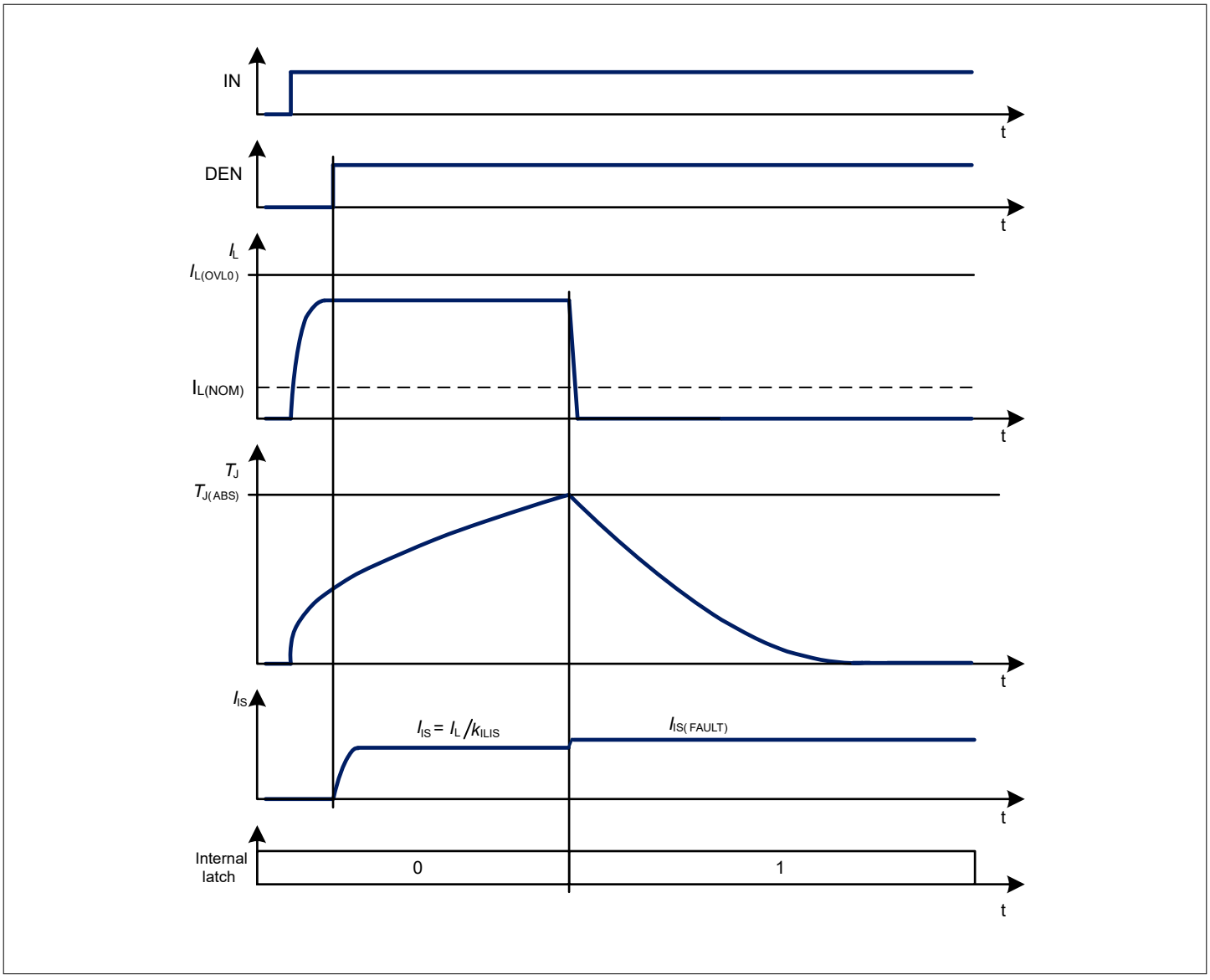


Figure 19 Overtemperature Protection (Absolute)

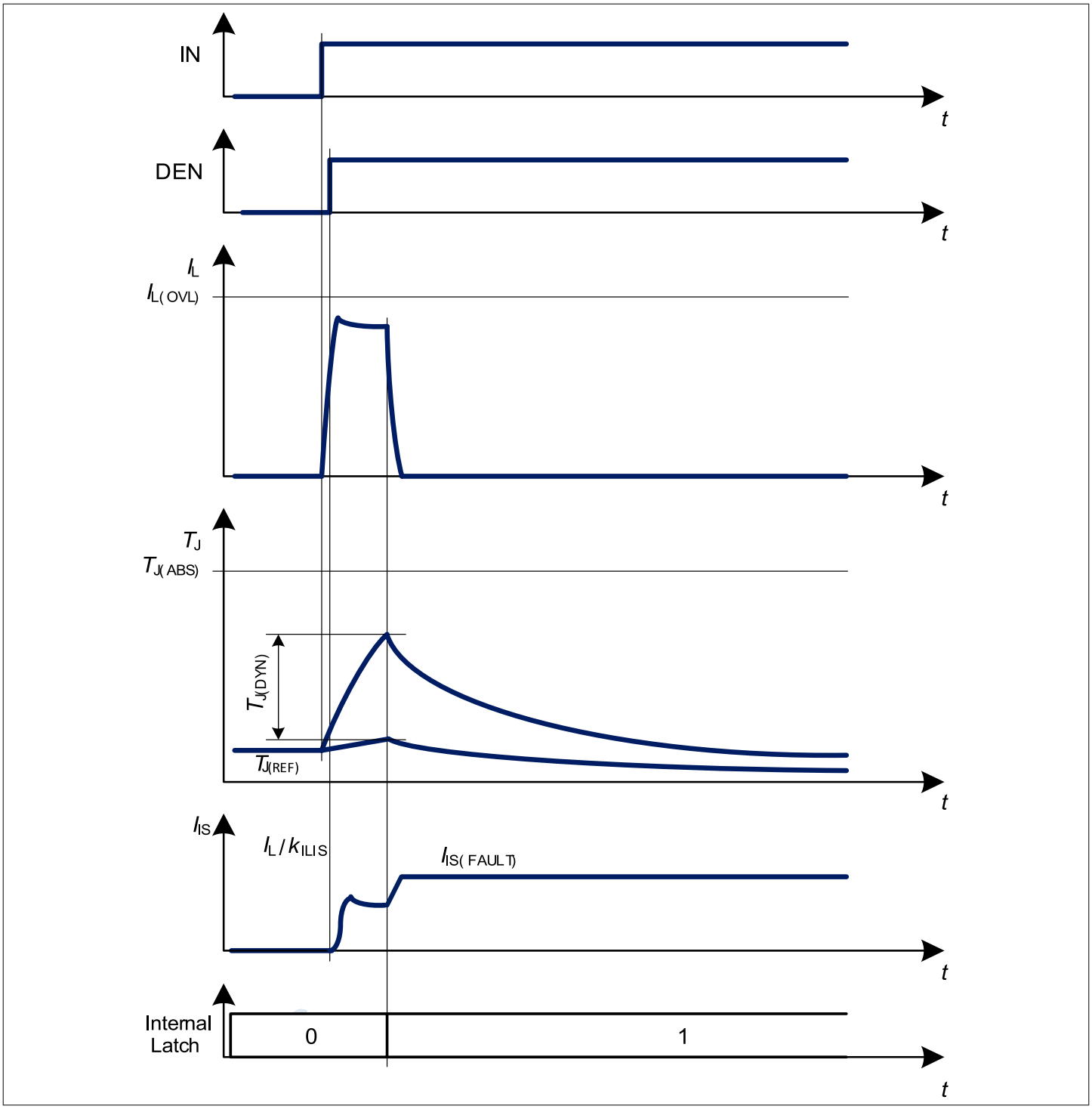


Figure 20 Overtemperature Protection (Dynamic)

When the Overtemperature protection circuitry allows the channel to be switched ON again, the Intelligent Latch strategy described in Chapter 8.3 is followed.

8.2 Overload Protection

The BTS7004-1EPR is protected in case of Overload or short circuit to ground. Two Overload thresholds are defined (see Figure 21) and selected automatically depending on the voltage V_{DS} across the power DMOS:

- $I_{L(OVL0)}$ when V_{DS} < 13 V
- $I_{L(OVL1)}$ when V_{DS} > 22 V

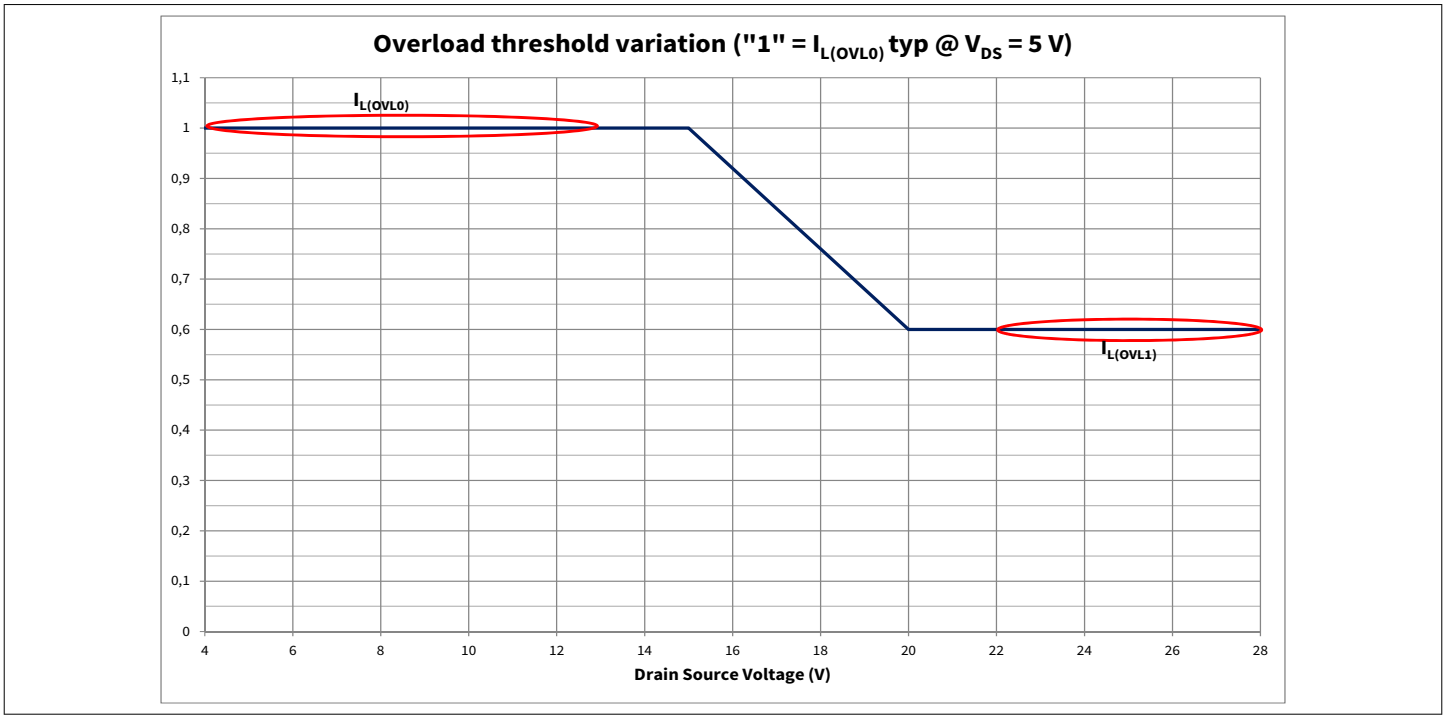


Figure 21 Overload Current Thresholds

In order to allow a higher load inrush at low ambient temperature, Overload threshold is maximum at low temperature and decreases when T_J increases (see Figure 22). $I_{L(OVL0)}$ typical value remains approximately constant up to a junction temperature of +75 °C.

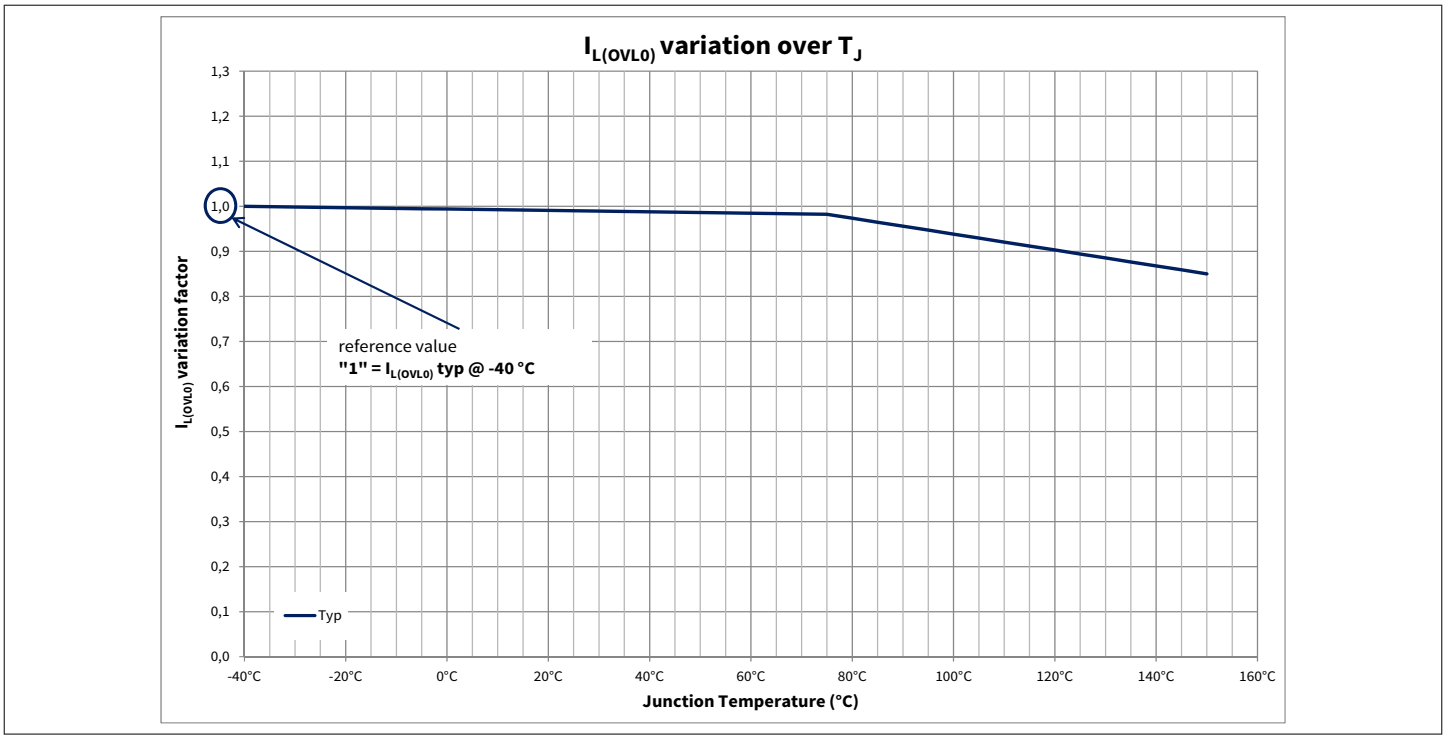


Figure 22 Overload Current Thresholds variation with T_J

Power supply voltage V_S can increase above 18 V for short time, for instance in Load Dump or in Jump Start condition. Whenever $V_S \geq V_{S(JS)}$, the overload detection current is set to $I_{L(OVL\_JS)}$ as shown in Figure 23.

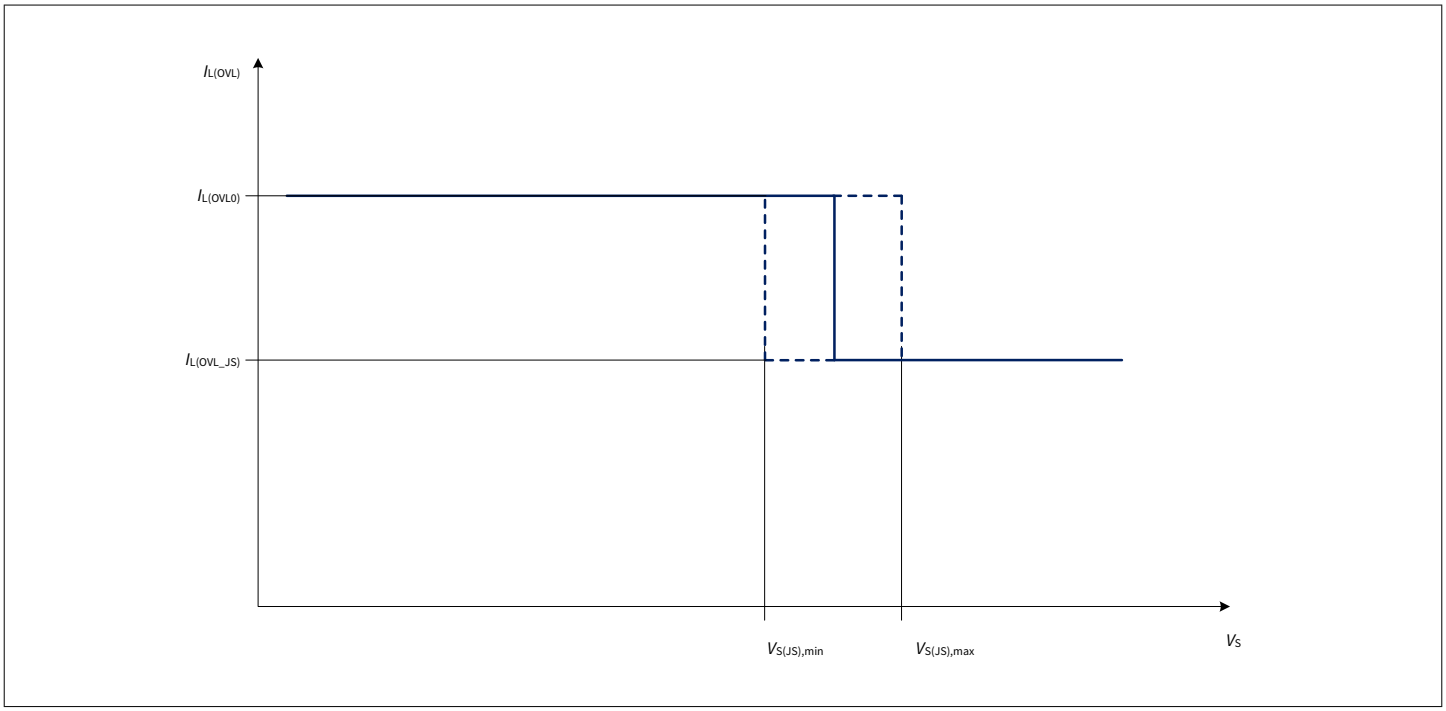


Figure 23 Overload Detection Current variation with V_S voltage

When $I_L \geq I_{L(OVL)}$ (either $I_{L(OVL0)}$, $I_{L(OVL1)}$ or $I_{L(OVL\_JS)}$) the channel is switched OFF. The channel is allowed to be reactivated according to the intelligent latch strategy described in Chapter 8.3.

8.3 Protection and Diagnosis in case of Fault

Any event that triggers a protection mechanism (either Overtemperature or Overload) has 2 consequences:

- The channel switches OFF and the internal latch is set to “1”
- If the diagnosis is active for the channel, a current $I_{IS(FAULT)}$ is provided by IS pin (see Chapter 9.2.2 for further details)

The channel can be switched ON again if all the protection mechanisms fulfill the ”reactivation” conditions described in Table 14. Furthermore, the device has the intelligent latch to protect itself against unwanted repetitive reactivation in fault condition.

Table 14 Protection “Reactivation” Condition

Fault condition	Switch OFF event	“Reactivation” condition
Overtemperature	$T_J \geq T_{J(ABS)}$ or $(T_J - T_{J(REF)}) \geq T_{J(DYN)}$	$T_J < T_{J(ABS)}$ and $(T_J - T_{J(REF)}) < T_{J(DYN)}$ (including hysteresis)
Overload	$I_L \geq I_{L(OVL)}$	$I_L < 50$ mA, T_J within $T_{J(ABS)}$ and $T_{J(DYN)}$ ranges (including hysteresis)

8.3.1 Intelligent Latch Strategy

At normal condition, when IN is set to “high”, the channel is switched ON. In case of fault condition the output stage latches OFF. There are two ways to de-latch the switch.

With IN pin:

It is necessary to set the input pin to “low” for a time longer than $t_{DELAY(LR)}$ (“latch reset delay” time) to de-latch the channel. The channel can be allowed to restart only if the “latch” conditions for the protection mechanisms are fulfilled (see Table 14).

During the “latch reset delay” time, if the input is set to “high” the channel remains switched OFF and the timer $t_{DELAY(LR)}$ is reset. The timer $t_{DELAY(LR)}$ restarts as soon as the input pin is set to “low” again.

The intelligent latch strategy is shown in Figure 26 (flowchart) and Figure 24 (timing diagram).

With DEN pin:

It is possible to “force” a reset of the internal latch without waiting for $t_{DELAY(LR)}$ by applying a pulse (rising edge followed by a falling edge) to the DEN pin while IN pin is “low”. The pulse applied to DEN pin must have a duration longer than $t_{DEN(LR)}$ to ensure a reset of the internal latch.

The timing is shown in Figure 25.

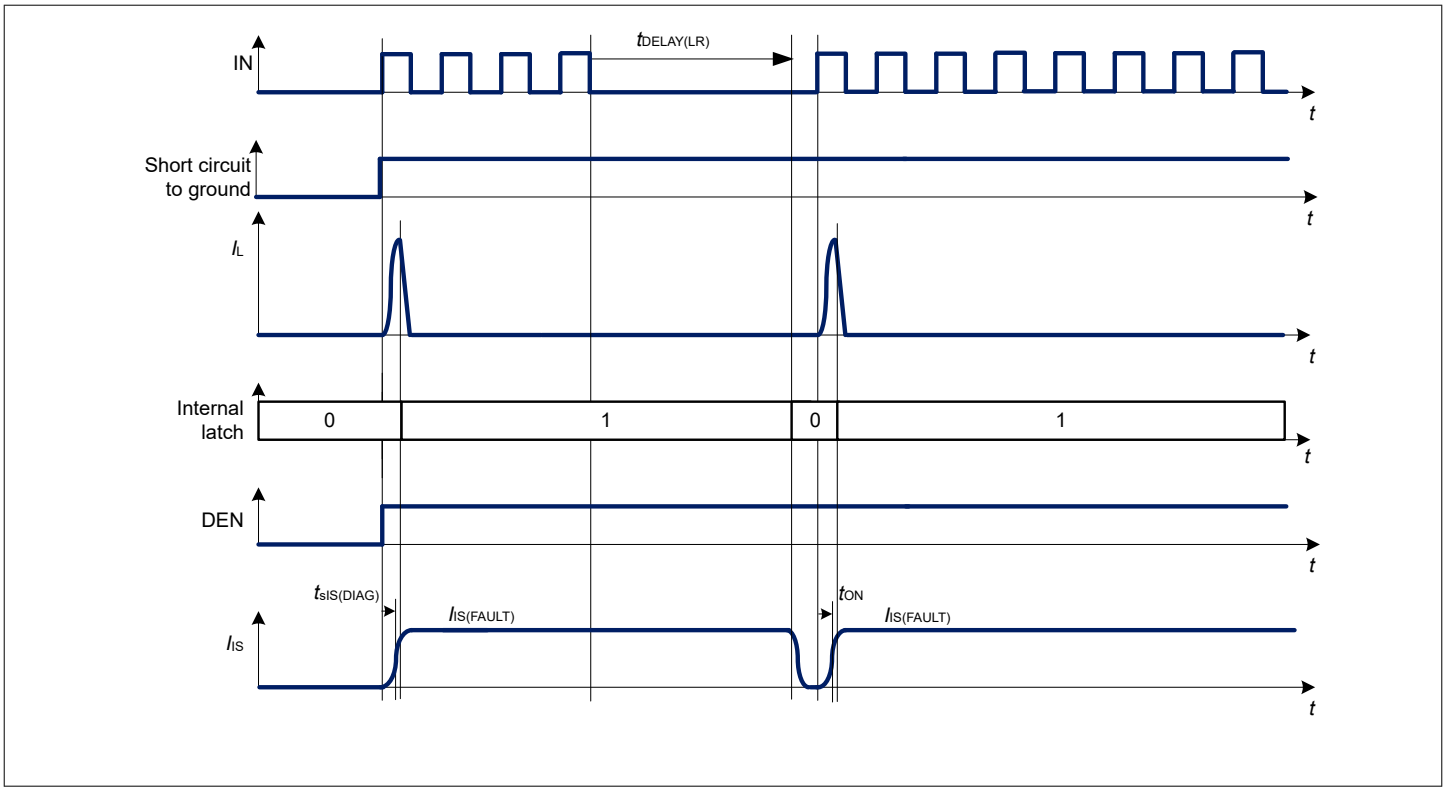


Figure 24 Intelligent Latch Timing Diagram

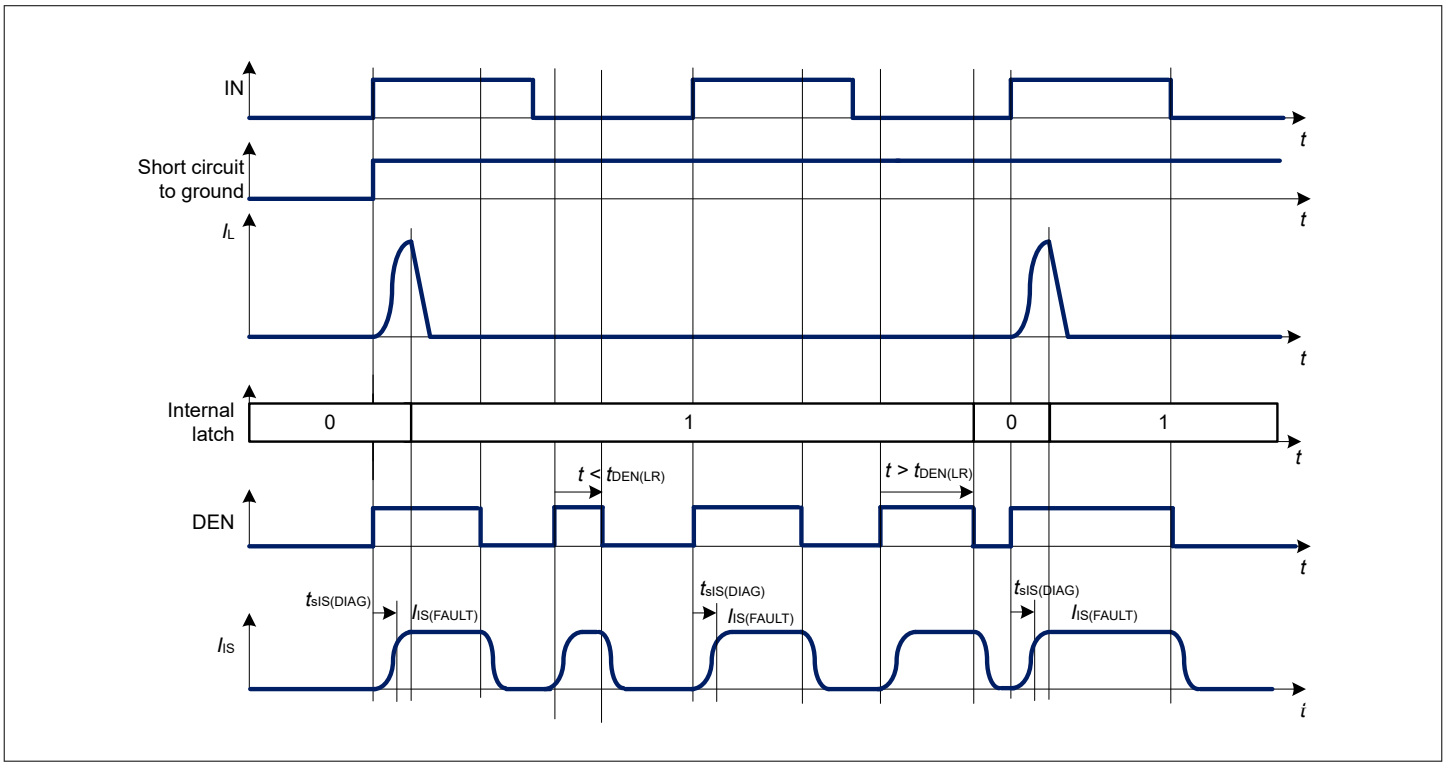


Figure 25 Intelligent Latch Timing Diagram with Forced Reset

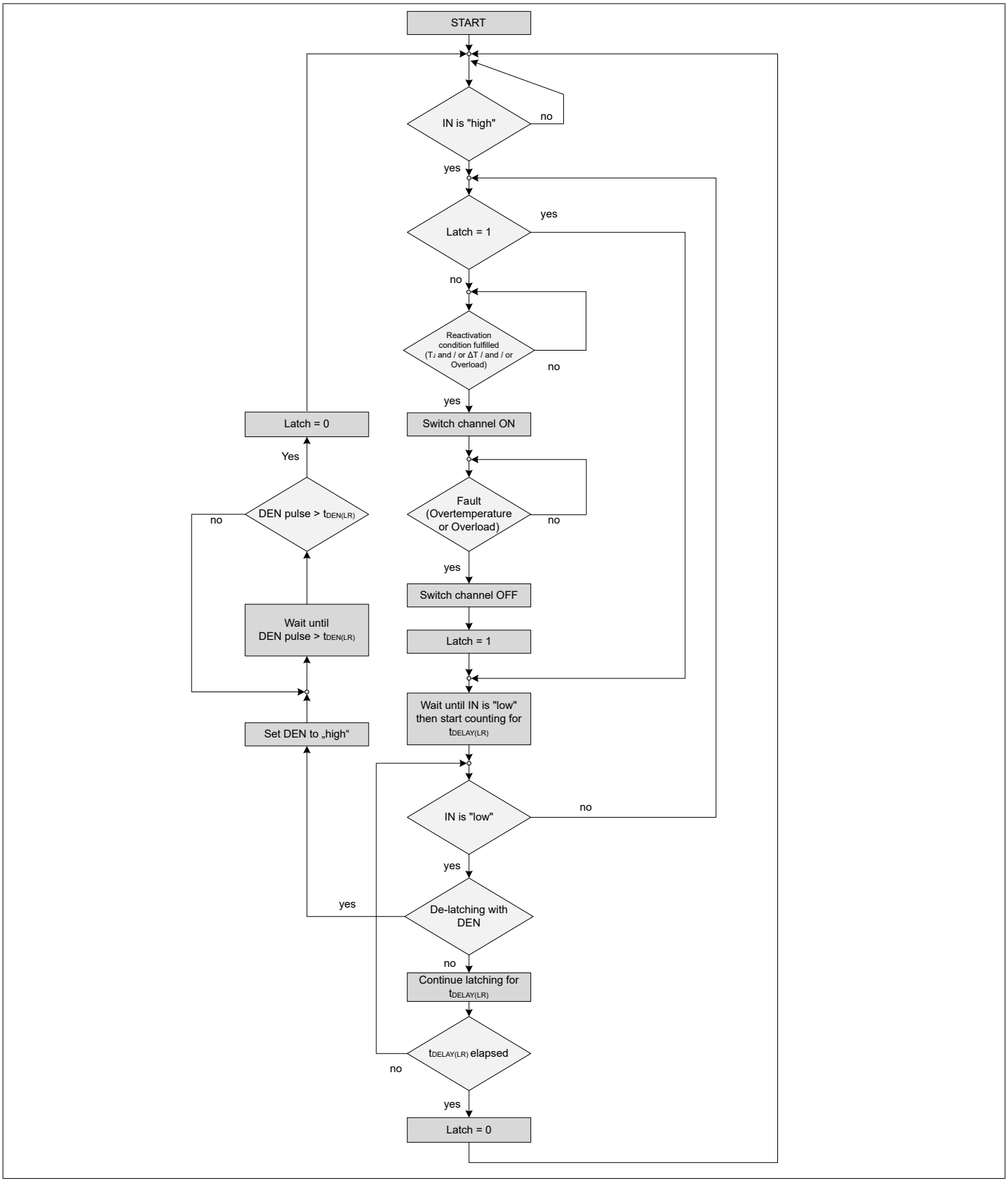


Figure 26 Intelligent Latch Flowchart

8.4 Additional protections

8.4.1 Reverse Polarity Protection

In Reverse Polarity condition (also known as Reverse Battery), the output stage is switched ON (see parameter $R_{DS(REV)}$) because of ReverseON feature which limits the power dissipation in the output stage. Each ESD diode of the logic contributes to total power dissipation. The reverse current through the output stage must be limited by the connected load. The current through Digital Input pins has to be limited as well by an external resistor (please refer to the Absolute Maximum Ratings listed in Chapter 4.1 and to Application Information in Chapter 10).

Figure 27 shows a typical application including a device with ReverseON. A current flowing into GND pin ($-I_{GND}$) during Reverse Polarity condition is necessary to activate ReverseON, therefore a resistive path between module ground and device GND pin must be present.

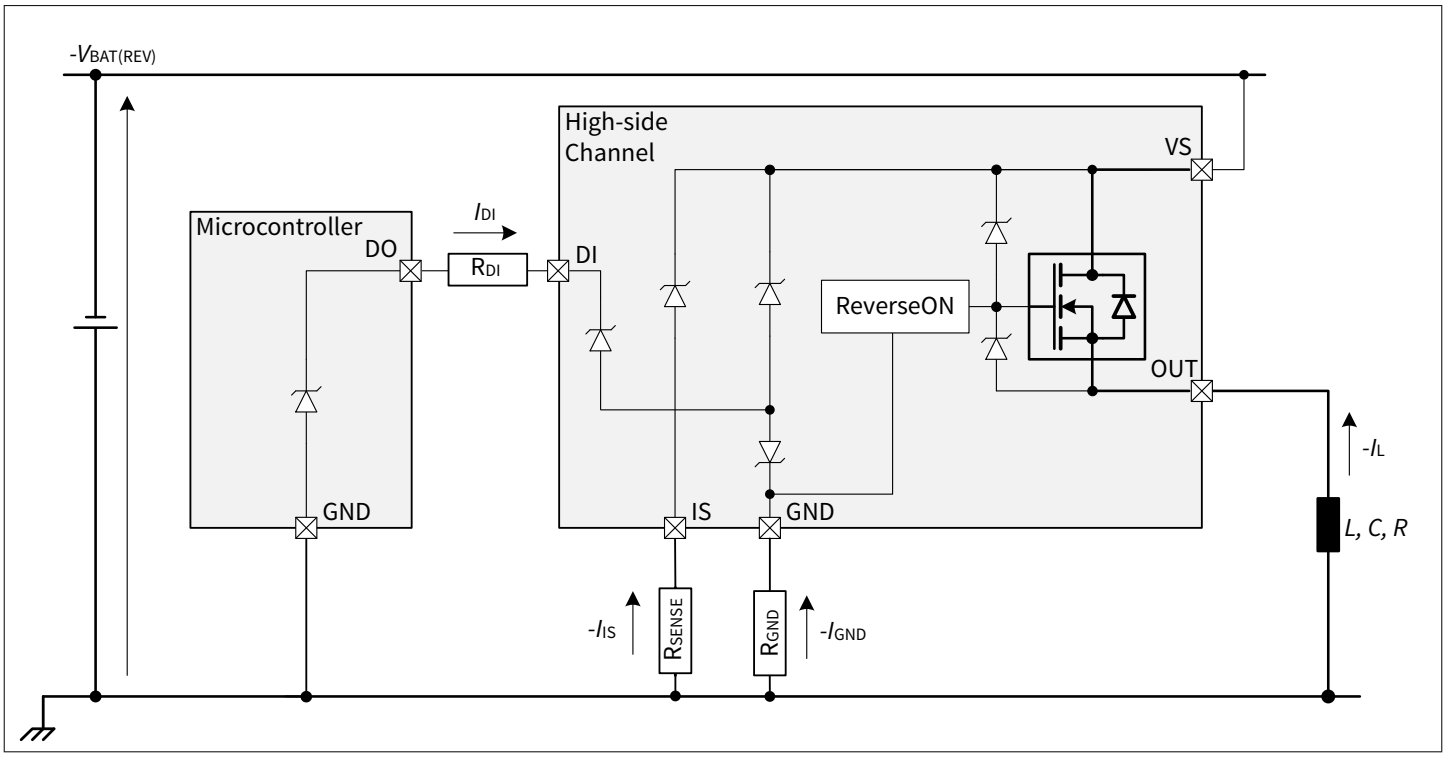


Figure 27 Reverse Battery Protection (application example)

8.4.2 Overvoltage Protection

In the case of supply voltages between $V_{S(EXT,UP)}$ and $V_{BAT(LD)}$, the output transistor is still operational and follows the input pin. In addition to the output clamp for inductive loads as described in Chapter 7.2.2, there is a clamp mechanism available for Overvoltage protection for the logic circuit and the output channel, monitoring the voltage between VS and GND pins ($V_{S(CLAMP)}$).

8.5 Protection against loss of connection

8.5.1 Loss of Battery and Loss of Load

The loss of connection to battery or to the load has no influence on device robustness when load and wire harness are purely resistive. In case of driving an inductive load, the energy stored in the inductance must be handled. PROFET™ +2 12V devices can handle the inductivity of the wire harness up to 10 µH with $I_{L(NOM)}$. In case of applications where currents and/or the aforementioned inductivity are exceeded, an external suppressor diode (like diode D_{Z2} shown in Chapter 10) is recommended to handle the energy and to provide a well-defined path to the load current.

8.5.2 Loss of Ground

In case of loss of device ground, it is recommended to have a resistor connected between any Digital Input pin and the microcontroller to ensure a channel switch OFF (as described in Chapter 10).

***Note**: In case any Digital Input pin is pulled to ground (either by a resistor or active) a parasitic ground path is available, which could keep the device operational during loss of device ground.*

8.6 Electrical Characteristics Protection

V_S = 6 V to 18 V, T_J = -40 °C to +150 °C
Typical values: V_S = 13.5 V, T_J = 25 °C
Typical resistive load connected to the output for testing (unless otherwise specified):
R_L = 4 Ω

Table 15 Electrical Characteristics: Protection - General

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Thermal Shutdown Temperature (Absolute)	$T_{J(ABS)}$	150	175	200	°C	1) 2) See Figure 19	P_8.6.0.1
Thermal Shutdown Hysteresis (Absolute)	$T_{HYS(ABS)}$	–	30	–	K	3) See Figure 19	P_8.6.0.2
Thermal Shutdown Temperature (Dynamic)	$T_{J(DYN)}$	–	80	–	K	3) See Figure 20	P_8.6.0.3
Power Supply Clamping Voltage at T_J = -40 °C	$V_{S(CLAMP)\_-40}$	33	36.5	42	V	I_{VS} = 5 mA T_J = -40 °C See Figure 15	P_8.6.0.6
Power Supply Clamping Voltage at $T_J \geq$ 25 °C	$V_{S(CLAMP)\_25}$	35	38	44	V	2) I_{VS} = 5 mA $T_J \geq$ 25°C See Figure 15	P_8.6.0.7
Power Supply Voltage Threshold for Overcurrent Threshold Reduction in case of Short Circuit	$V_{S(JS)}$	20.5	22.5	24.5	V	3) Setup acc. to AEC-Q100-012	P_8.6.0.8

1) Functional test only.
2) Tested at T_J = 150°C only.
3) Not subject to production test - specified by design.

8.6.1 Electrical Characteristics Protection

Table 16 Electrical Characteristics: Protection

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Latch Reset Delay Time after Fault Condition	$t_{DELAY(LR)}$	40	70	100	ms	1) See Figure 24	P_8.6.4.1
Minimum DEN Pulse Duration for Latch Reset	$t_{DEN(LR)}$	50	100	150	µs	2) See Figure 25	P_8.6.4.2

1) Functional test only.
2) Not subject to production test - specified by design.

8.7 Electrical Characteristics Protection - Power Output Stages

V_S = 6 V to 18 V, T_J = -40 °C to +150 °C
Typical values: V_S = 13.5 V, T_J = 25 °C
Typical resistive load connected to the output for testing (unless otherwise specified):
R_L = 4 Ω

8.7.1 Protection Power Output Stage - 4 mΩ

Table 17 Electrical Characteristics: Protection - 4 mΩ

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Overload Detection Current at T_J = -40 °C	$I_{L(OVL0)\_-40}$	87	102	117	A	1) T_J = -40 °C dI/dt = 0.4 A/µs See Figure 21 and Figure 22	P_8.7.29.1
Overload Detection Current at T_J = 25 °C	$I_{L(OVL0)\_25}$	86	100	114	A	2) T_J = 25 °C dI /dt = 0.4 A/µs See Figure 21 and Figure 22	P_8.7.29.2
Overload Detection Current at T_J = 150 °C	$I_{L(OVL0)\_150}$	73	85	97	A	2) T_J = 150 °C dI /dt = 0.4 A/µs See Figure 21 and Figure 22	P_8.7.29.3
Overload Detection Current at High V_{DS}	$I_{L(OVL1)}$	–	61	–	A	2) dI /dt = 0.4 A/µs See Figure 21	P_8.7.29.4
Overload Detection Current Jump Start Condition	$I_{L(OVL\_JS)}$	–	61	–	A	2) $V_S > V_{S(JS)}$ dI /dt = 0.4 A/µs	P_8.7.29.5

1) Functional test only.
2) Not subject to production test - specified by design.

9 Diagnosis

For diagnosis purpose, the BTS7004-1EPR provides a sense current signal (I_{IS}) at pin IS. In case of disabled diagnostic (DEN pin set to “low”), IS pin becomes high impedance.

A sense resistor R_{SENSE} must be connected between IS pin and module ground if the current sense diagnosis is used. R_{SENSE} value has to be higher than 820 Ω (or 400 Ω when a central Reverse Battery protection is present on the battery feed) to limit the power losses in the sense circuitry. A typical value is R_{SENSE} = 1.2 kΩ.

Due to the internal connection between IS pin and V_S supply voltage, it is not recommended to connect the IS pin to the sense current output of other devices, if they are supplied by a different battery feed.

See Figure 28 for details as an overview.

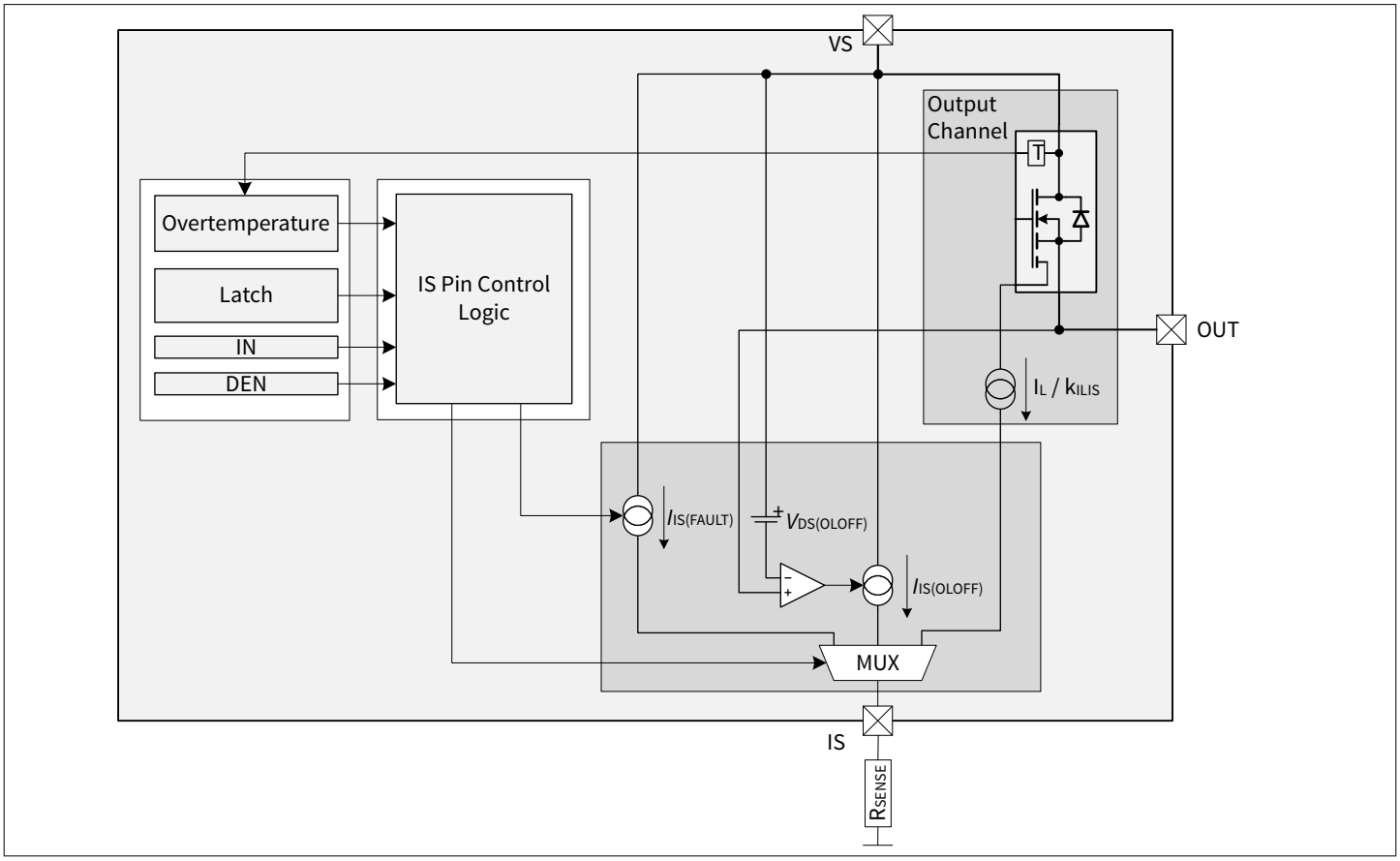


Figure 28 Diagnosis Block Diagram

9.1 Overview

Table 18 gives a quick reference to the state of the IS pin during BTS7004-1EPR operation.

Table 18 SENSE Signal, Function of Application Condition

Application Condition	Input level	DEN level	V_{OUT}	Diagnostic Output
Normal operation	"low"	"high"	~ GND	Z $I_{IS(FAULT)}$ if latch ≠ 0
Short circuit to GND			~ GND	Z $I_{IS(FAULT)}$ if latch ≠ 0
Overtemperature			Z	$I_{IS(FAULT)}$
Short circuit to V_S			V_S	$I_{IS(OLOFF)}$ ($I_{IS(FAULT)}$ if latch ≠ 0)
Open Load			< V_S - $V_{DS(OLOFF)}$ > V_S - $V_{DS(OLOFF)}$ 1)	Z $I_{IS(OLOFF)}$ (in both cases $I_{IS(FAULT)}$ if latch ≠ 0)
Inverse current			V_{OUT} > V_S	$I_{IS(OLOFF)}$ ($I_{IS(FAULT)}$ if latch ≠ 0)
Normal operation	"high"		~ V_S	$I_{IS} = I_L / k_{ILIS}$
Overcurrent			< V_S	$I_{IS(FAULT)}$
Short circuit to GND			~ GND	$I_{IS(FAULT)}$
Overtemperature			Z	$I_{IS(FAULT)}$
Short circuit to V_S			V_S	$I_{IS} < I_L / k_{ILIS}$
Open Load			~ V_S 2)	$I_{IS} = I_{IS(EN)}$
Under load (e.g. Output Voltage Limitation condition)			~ V_S 3)	$I_{IS(EN)} < I_{IS} < I_{L(NOM)} / k_{ILIS}$
Inverse current			V_{OUT} > V_S	$I_{IS} = I_{IS(EN)}$
All conditions	n.a.	"low"	n.a.	Z

1) With additional pull-up resistor.
2) The output current has to be smaller than $I_{L(OL)}$.
3) The output current has to be higher than $I_{L(OL)}$.

9.2 Diagnosis in ON state

A current proportional to the load current (ratio $k_{ILIS} = I_L / I_{IS}$) is provided at pin IS when the following conditions are fulfilled:

- The power output stage is switched ON with $V_{DS} < V_{DS(OLOFF)}$
- The diagnosis is enabled
- No fault (as described in Chapter 8.3) is present or was present and not cleared yet (see Chapter 9.2.2 for further details)

If a "hard" failure mode is present or was present and not cleared yet a current $I_{IS(FAULT)}$ is provided at IS pin .

9.2.1 Current Sense (k_{ILIS})

The accuracy of the sense current depends on temperature and load current. I_{IS} increases linearly with I_L output current until it reaches the saturation current $I_{IS(SAT)}$. In case of Open Load at the output stage (I_L close to 0 A), the maximum sense current $I_{IS(EN)}$ (no load, diagnosis enabled) is specified. This condition is shown in Figure 30. The blue line represents the ideal k_{ILIS} line, while the red lines show the behavior of a typical product.

An external RC filter between IS pin and microcontroller ADC input pin is recommended to reduce signal ripple and oscillations (a minimum time constant of 1 µs for the RC filter is recommended).

The k_{ILIS} factor is specified with limits that take into account effects due to temperature, supply voltage and manufacturing process. Tighter limits are possible (within a defined current window) with calibration:

- A well-defined and precise current ($I_{L(CAL)}$) is applied at the output during End of Line test at customer side
- The corresponding current at IS pin is measured and the k_{ILIS} is calculated (k_{ILIS} @ $I_{L(CAL)}$)
- Within the current range going from $I_{L(CAL)\_L}$ to $I_{L(CAL)\_H}$ the k_{ILIS} is equal to k_{ILIS} @ $I_{L(CAL)}$ with limits defined by Δk_{ILIS}

The derating of k_{ILIS} after calibration is calculated using the formulas in Figure 29 and it is specified by Δk_{ILIS}

$$\Delta k_{ILIS,MAX} = 100 \cdot MAX\left(\frac{k_{ILIS}@I_{L(CAL)\_L}}{k_{ILIS}@I_{L(CAL)}} - 1, \frac{k_{ILIS}@I_{L(CAL)\_H}}{k_{ILIS}@I_{L(CAL)}} - 1\right)$$

$$\Delta k_{ILIS,MIN} = 100 \cdot MIN\left(\frac{k_{ILIS}@I_{L(CAL)\_L}}{k_{ILIS}@I_{L(CAL)}} - 1, \frac{k_{ILIS}@I_{L(CAL)\_H}}{k_{ILIS}@I_{L(CAL)}} - 1\right)$$

Figure 29 Δk_{ILIS} calculation formulas

The calibration is intended to be performed at $T_{A(CAL)}$ = 25°C. The parameter Δk_{ILIS} includes the drift overtemperature as well as the drift over the current range from $I_{L(CAL)\_L}$ to $I_{L(CAL)\_H}$.

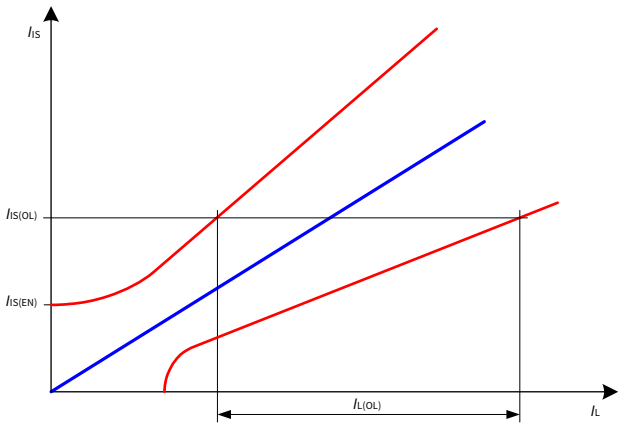


Figure 30 Current Sense Ratio in Open Load at ON condition

9.2.2 Fault Current ($I_{IS(FAULT)}$)

As soon as a protection event occurs, the value of the internal latch (see Chapter 8.3 for more details) is changed from 0 to 1, and a current $I_{IS(FAULT)}$ is provided by pin IS when DEN is set to “high”.

If internal latch is 1, and it is not reset, the current $I_{IS(FAULT)}$ is provided each time the device diagnosis is activated by DEN=High.

Figure 31 shows the relation between $I_{IS} = I_L / k_{ILIS}$, $I_{IS(SAT)}$ and $I_{IS(FAULT)}$.

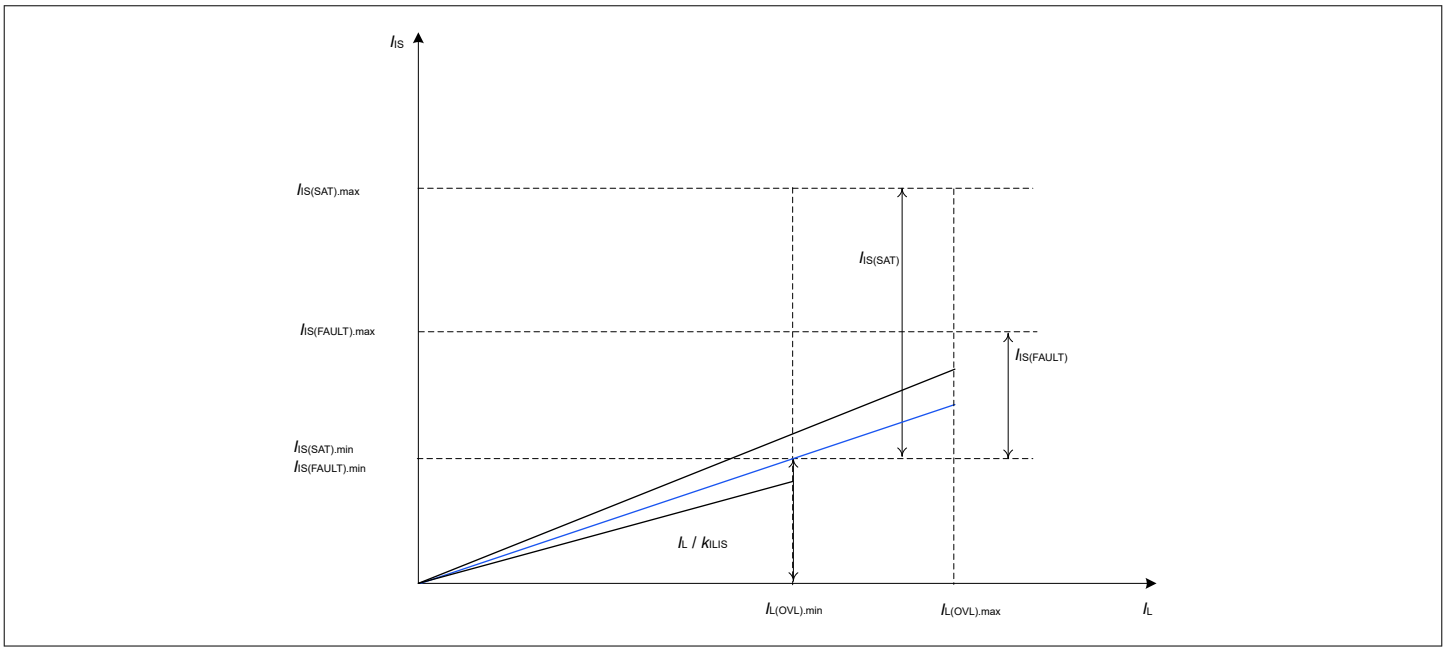


Figure 31 SENSE behavior - overview

9.3 Diagnosis in OFF state

When a power output stage is in OFF state, the BTS7004-1EPR can measure the drain-source voltage and compare it with a threshold voltage. In this way, using some additional external components (a pull-down resistor and a switchable pull-up current source), it is possible to detect if the load is missing or if there is a short circuit to battery. If a Fault condition was detected by the device (if internal latch is 1, fault current is provided by IS pin independent of drain-source or output voltage, as long as DEN=High) a current $I_{IS(FAULT)}$ is provided by IS pin each time the channel diagnosis is checked also in OFF state. See Chapter 9.2.2 for further details.

9.3.1 Open Load current ($I_{IS(OLOFF)}$)

In OFF state, when DEN pin is set to “high”, the V_{DS} voltage is compared with a threshold voltage $V_{DS(OLOFF)}$. If the load is properly connected and there is no short circuit to battery, $V_{DS} \sim V_S$ therefore $V_{DS} > V_{DS(OLOFF)}$. When the diagnosis is active and $V_{DS} \leq V_{DS(OLOFF)}$, a current $I_{IS(OLOFF)}$ is provided by IS pin. Figure 32 shows the relationship between $I_{IS(OLOFF)}$ and $I_{IS(FAULT)}$ as functions of V_{DS}. The two currents do not overlap making it always possible to differentiate between Open Load in OFF and Fault condition.

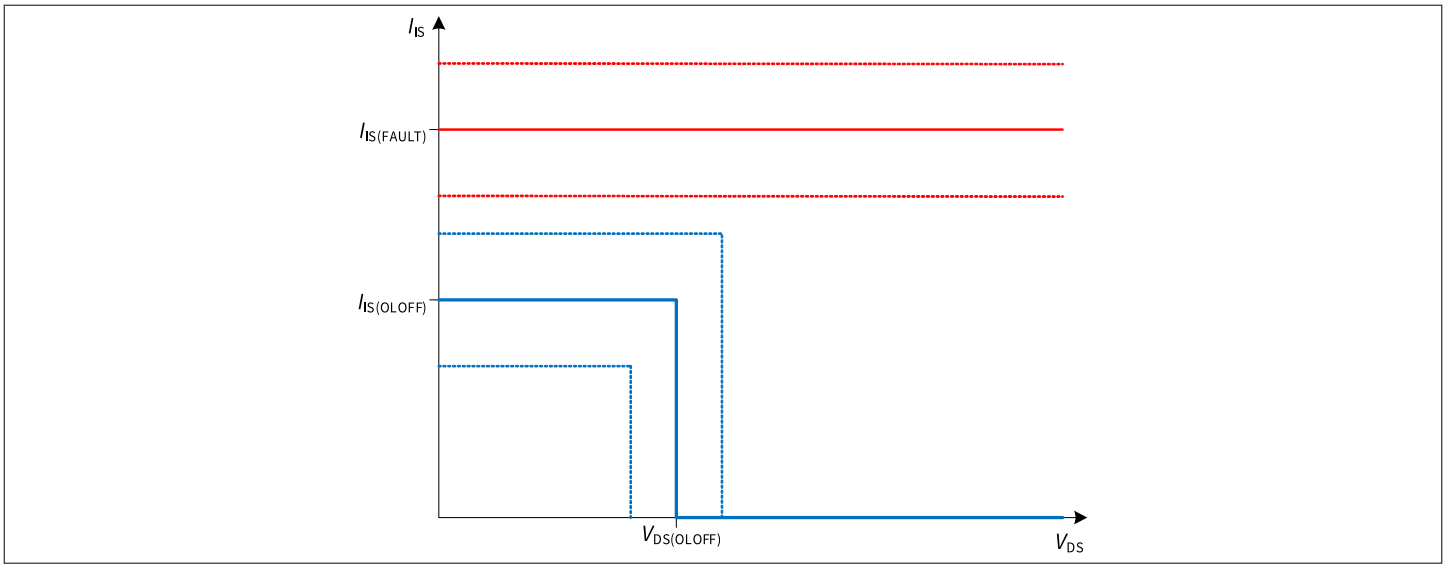


Figure 32 I_{IS} in OFF State

It is necessary to wait a time $t_{IS(OLOFF)\_D}$ between the falling edge of the input pin and the sensing at pin IS for Open Load in OFF diagnosis to allow the internal comparator to settle. In Figure 33 the timings for an Open Load detection are shown - the load is always disconnected.

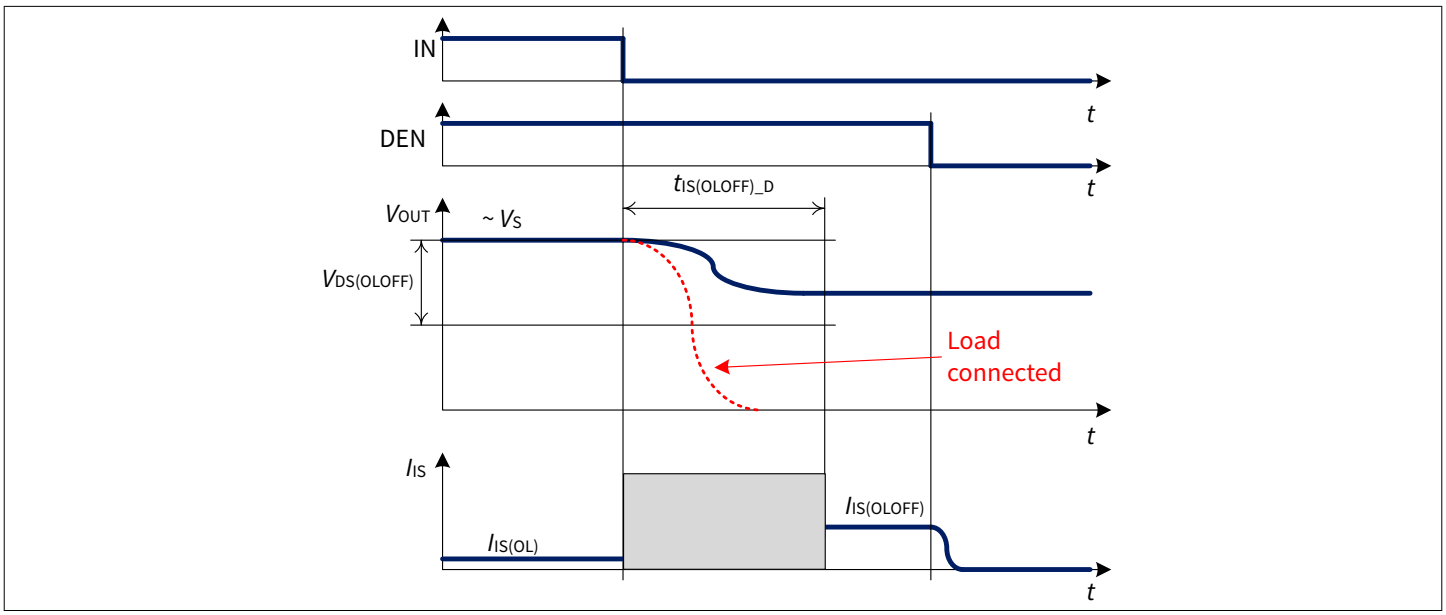


Figure 33 Open Load in OFF Timings - load disconnected

9.4 SENSE Timings

Figure 34 shows the timing during settling $t_{sIS(ON)}$ and disabling $t_{sIS(OFF)}$ of the SENSE (including the case of load change). As a proper signal cannot be established before the load current is stable (therefore before t_{ON}), $t_{sIS(DIAG)} \leq 3 \times (t_{ON\_max} + t_{sIS(ON)\_max})$.

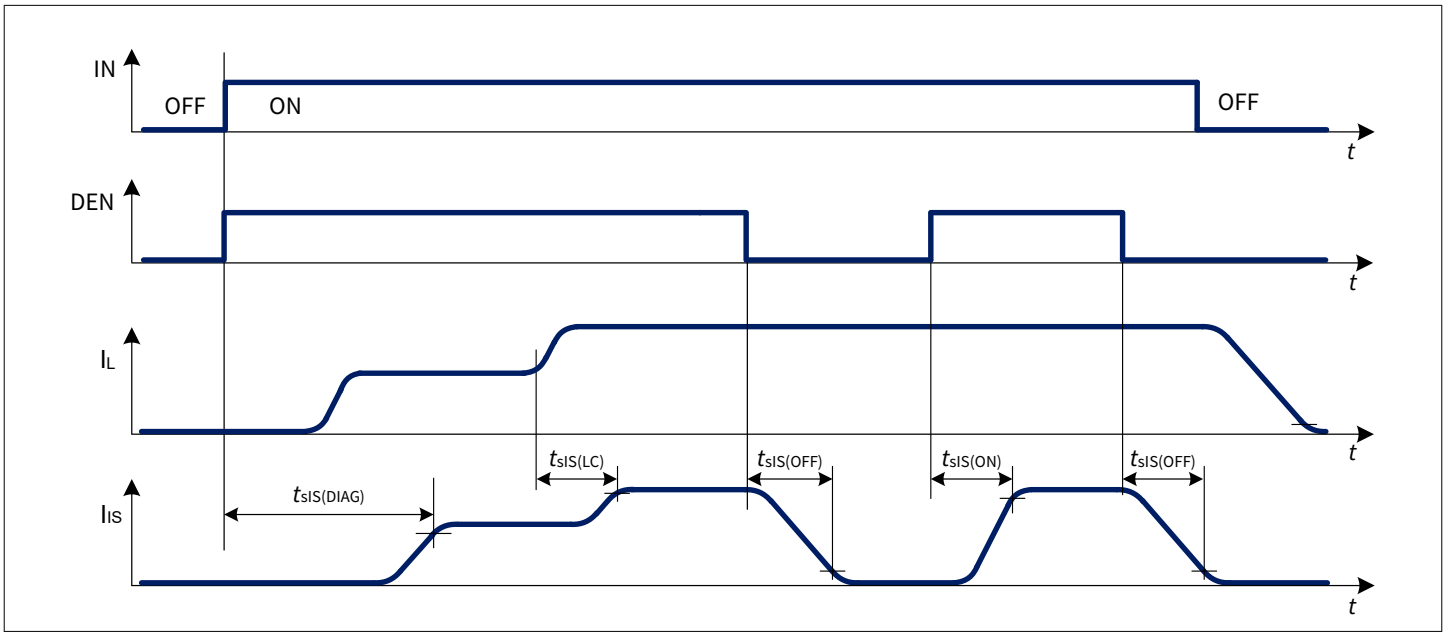


Figure 34 SENSE Settling / Disabling Timing

9.5 Electrical Characteristics Diagnosis

V_S = 6 V to 18 V, T_J = -40 °C to +150 °C
Typical values: V_S = 13.5 V, T_J = 25 °C
Typical resistive load connected to the output for testing (unless otherwise specified):
R_L = 4 Ω

Table 19 Electrical Characteristics: Diagnosis - General

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
SENSE Saturation Current	$I_{IS(SAT)}$	4.4	–	15	mA	1) $V_{SIS} = V_S - V_{IS} \geq 2$ V See Figure 31	P_9.6.0.1
SENSE Leakage Current when Disabled	$I_{IS(OFF)}$	–	0.01	0.5	µA	DEN = “low” V_{IS} = 0 V	P_9.6.0.2
SENSE Leakage Current when Enabled at $T_J \leq 85$ °C	$I_{IS(EN)\_85}$	–	0.2	1	µA	1) $T_J \leq 85$°C DEN = “high” I_L = 0 A See Figure 30	P_9.6.0.3
SENSE Leakage Current when Enabled at T_J = 150 °C	$I_{IS(EN)\_150}$	–	0.2	1	µA	T_J = 150 °C DEN = “high” I_L = 0 A See Figure 30	P_9.6.0.4
Saturation Voltage in k_{ILIS} Operation (V_S - V_{IS})	V_{SIS_k}	–	0.5	1	V	1) V_S = 6 V IN = DEN = “high” $I_L \leq 2 * I_{L(NOM)}$	P_9.6.0.6
Saturation Voltage in Open Load at OFF Diagnosis (V_S - V_{IS})	V_{SIS_OL}	–	0.5	1	V	1) V_S = 6 V IN = “low” DEN = “high”	P_9.6.0.7
Saturation Voltage in Fault Diagnosis (V_S - V_{IS})	V_{SIS_F}	–	0.5	1	V	1) V_S = 6 V IN = “low” DEN = “high” latch ≠ 0	P_9.6.0.8
Power Supply to IS Pin Clamping Voltage at T_J = -40 °C	$V_{SIS(CLAMP)\_-40}$	33	36.5	42	V	I_{IS} = 1 mA T_J = -40 °C See Figure 15	P_9.6.0.9

(table continues...)

Table 19 (continued) Electrical Characteristics: Diagnosis - General

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Power Supply to IS Pin Clamping Voltage at $T_J \geq 25$ °C	$V_{SIS(CLAMP)\_25}$	35	38	44	V	2) I_{IS} = 1 mA $T_J \geq 25$ °C See Figure 15	P_9.6.0.10

1) Not subject to production test - specified by design.
2) Tested at T_J = 150°C.

9.5.1 Electrical Characteristics Diagnosis

Table 20 Electrical Characteristics: Diagnosis

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
SENSE Fault Current	$I_{IS(FAULT)}$	4.4	5.5	10	mA	–	P_9.6.4.1
SENSE Open Load in OFF Current	$I_{IS(OLOFF)}$	1.8	2.5	3.5	mA	–	P_9.6.4.2
SENSE Open Load in OFF Delay Time	$t_{IS(OLOFF)\_D}$	70	200	400	µs	$V_{DS} < V_{OL(OFF)}$ from IN falling edge to $V_{IS} = R_{SENSE} * 0.9 * I_{IS(OLOFF), MIN}$ DEN = “high”	P_9.6.4.18
Open Load V_{DS} Detection Threshold in OFF State	$V_{DS(OLOFF)}$	1.3	1.8	2.3	V	–	P_9.6.4.5
SENSE Settling Time with Nominal Load Current Stable	$t_{sIS(ON)}$	–	5	40	µs	$I_L = I_{L(NOM)}$ DEN from “low” to “high”	P_9.6.4.6
SENSE Disable Time	$t_{sIS(OFF)}$	–	5	20	µs	1) From DEN falling edge to $I_{IS} = I_{IS(OFF)}$ See Figure 34	P_9.6.4.8
SENSE Settling Time after Load Change	$t_{sIS(LC)}$	–	5	20	µs	1) from $I_L = I_{L18}$ to $I_L = I_{L19}$ See Figure 34	P_9.6.4.9

(table continues...)

Table 20 (continued) Electrical Characteristics: Diagnosis

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
SENSE Settling Time after Load Change with Small Load Current	$t_{sIS(LC)\_SLC}$	–	3	–	ms	1) DEN = “high” from Load Change to $I_{IS} = I_L / (k_{ILIS} @ I_L)$ from $I_{L(CAL)}$ to $I_{L(CAL)\_OL}$	P_9.6.4.19
SENSE Settling Time with Small Load Current Stable	$t_{sIS(ON)\_SLC}$	–	1	–	ms	1) $I_L = I_{L(CAL)\_OL}$ from DEN rising edge to $I_{IS} = I_L / (k_{ILIS,MAX} @ I_L) * 0.9$	P_9.6.4.20

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

9.6 Electrical Characteristics Diagnosis - Power Output Stages

V_S = 6 V to 18 V, T_J = -40 °C to +150 °C
Typical values: V_S = 13.5 V, T_J = 25 °C
Typical resistive load connected to the output for testing (unless otherwise specified):
R_L = 4 Ω

9.6.1 Diagnosis Power Output Stage - 4 mΩ

Table 21 Electrical Characteristics Diagnosis - 4 mΩ

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Open Load Output Current at I_{IS} = 4 µA	$I_{L(OL)\_4u}$	45	80	115	mA	$I_{IS} = I_{IS(OL)}$ = 4 µA See Figure 30	P_9.7.34.1
Current Sense Ratio at $I_L = I_{L04}$	k_{ILIS04}	-65%	17900	+65%		I_{L04} = 50 mA	P_9.7.34.2
Current Sense Ratio at $I_L = I_{L07}$	k_{ILIS07}	-65%	17900	+65%		I_{L07} = 200 mA	P_9.7.34.3
Current Sense Ratio at $I_L = I_{L09}$	k_{ILIS09}	-55%	17900	+55%		I_{L09} = 450 mA	P_9.7.34.4
Current Sense Ratio at $I_L = I_{L13}$	k_{ILIS13}	-40%	17900	+40%		I_{L13} = 2 A	P_9.7.34.5
Current Sense Ratio at $I_L = I_{L16}$	k_{ILIS16}	-24%	17900	+24%		I_{L16} = 5.5 A	P_9.7.34.6
Current Sense Ratio at $I_L = I_{L18}$	k_{ILIS18}	-8%	17900	+8%		I_{L18} = 10 A	P_9.7.34.7
Current Sense Ratio at $I_L = I_{L19}$	k_{ILIS19}	-8%	17900	+8%		1) I_{L19} = 15 A	P_9.7.34.8
SENSE Current Derating with Low Current Calibration	$\Delta k_{ILIS(OL)}$	-30	0	+30	%	1) $I_{L(CAL)} = I_{L07}$ $I_{L(CAL)\_H} = I_{L09}$ $I_{L(CAL)\_L} = I_{L04}$ $T_{A(CAL)}$ = 25 °C	P_9.7.34.9
SENSE Current Derating with Nominal Current Calibration	$\Delta k_{ILIS(NOM)}$	-4	0	+4	%	1) $I_{L(CAL)} = I_{L18}$ $I_{L(CAL)\_H} = I_{L19}$ $I_{L(CAL)\_L} = I_{L16}$ $T_{A(CAL)}$ = 25 °C	P_9.7.34.10

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

10 Application Information

***Note**: The following information is given as a hint for the implementation of the device only and shall not be regarded as a description or warranty of a certain functionality, condition or quality of the device.*

10.1 Application setup

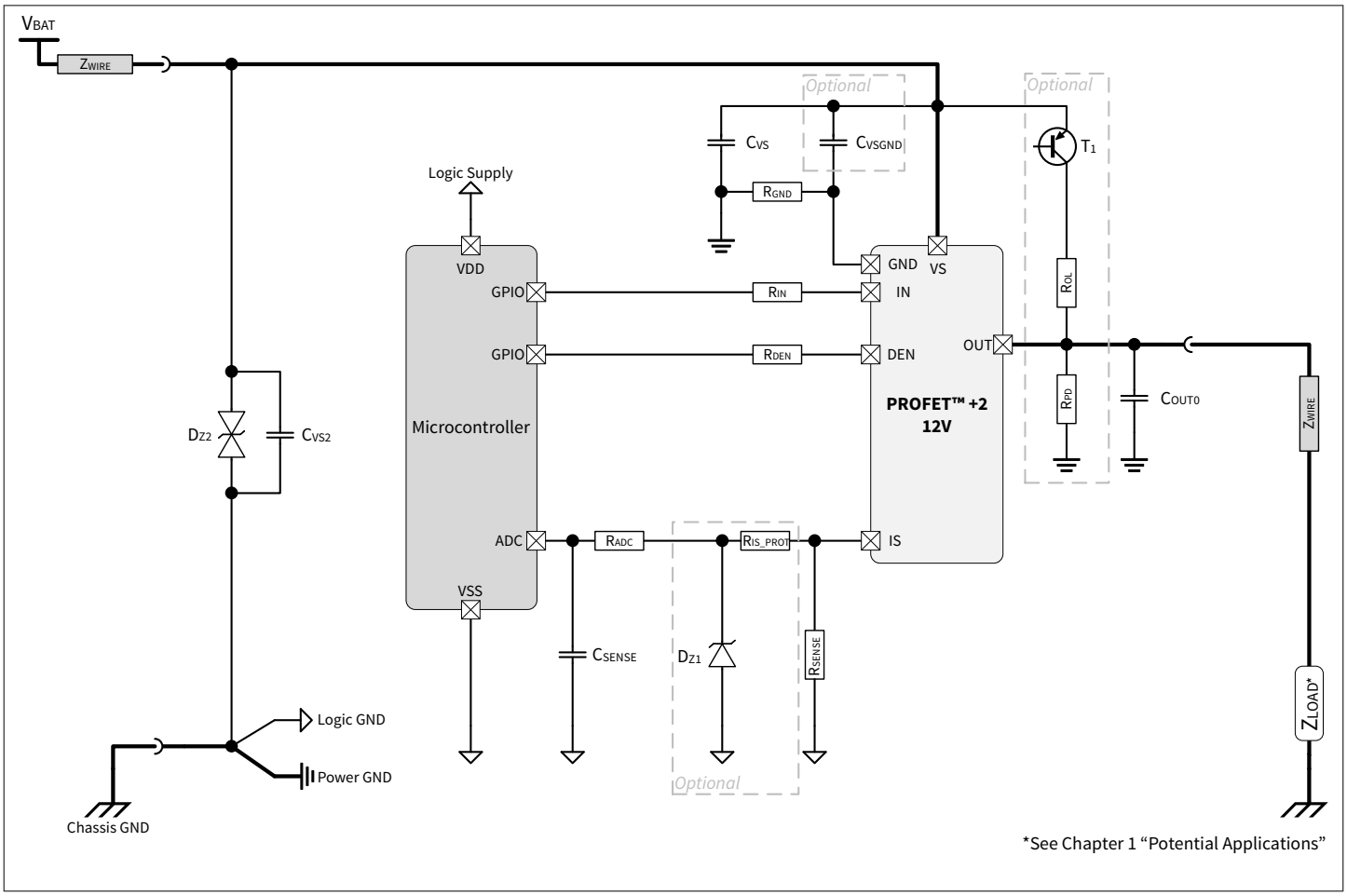


Figure 35 BTS7004-1EPR Application Diagram

***Note**: This is a very simplified example of an application circuit. The function must be verified in the real application.*

10.2 External Components

Table 22 Suggested Component values

Reference	Value	Purpose
R_{IN}	4.7 kΩ	Protection of the microcontroller during Overvoltage and Reverse Polarity Necessary to switch OFF BTS7004-1EPR output during Loss of Ground
R_{DEN}	4.7 kΩ	Protection of the microcontroller during Overvoltage and Reverse Polarity Necessary to switch OFF BTS7004-1EPR output during Loss of Ground
R_{PD}	47 kΩ	Output polarization (pull-down) Ensures polarization of BTS7004-1EPR outputs to distinguish between Open Load and Short to V_S in OFF Diagnosis
R_{OL}	1.5 kΩ	Output polarization (pull-up) Ensures polarization of BTS7004-1EPR output during Open Load in OFF diagnosis
C_{OUT}	10 nF	Protection of BTS7004-1EPR output during ESD events and BCI
T_1	BC 807	Switch the battery voltage for Open Load in OFF diagnosis
C_{VS}	100 nF	Filtering of voltage spikes on the battery line
C_{VSGND}	47 nF	Buffer capacitor for fast transient See Table 5 (P_4.3.0.7) for the boundary conditions A placeholder on PCB layout is recommended
D_{Z2}	33 V TVS Diode	Transient Voltage Suppressor diode Protection during Overvoltage and in case of Loss of Battery while driving an inductive load
C_{VS2}	–	Filtering / buffer capacitor located at V_{BAT} connector
R_{SENSE}	1.2 kΩ	SENSE resistor
R_{IS_PROT}	4.7 kΩ	Protection during Overvoltage, Reverse Polarity, Loss of Ground Value to be tuned according to microcontroller specifications
D_{Z1}	7 V Z-Diode	Protection of microcontroller during Overvoltage
R_{ADC}	4.7 kΩ	Protection of microcontroller ADC input during Overvoltage, Reverse Polarity, Loss of Ground Value to be tuned according to microcontroller specifications
C_{SENSE}	220 pF	Sense signal filtering A time constant longer than 1 µs is recommended
R_{GND}	47 Ω	Protection in case of Overvoltage and Loss of Battery while driving inductive loads

10.3 Further Application Information

- Please contact us for information regarding the Pin FMEA
- For further information you may contact http://www.infineon.com/

11 Package Outlines

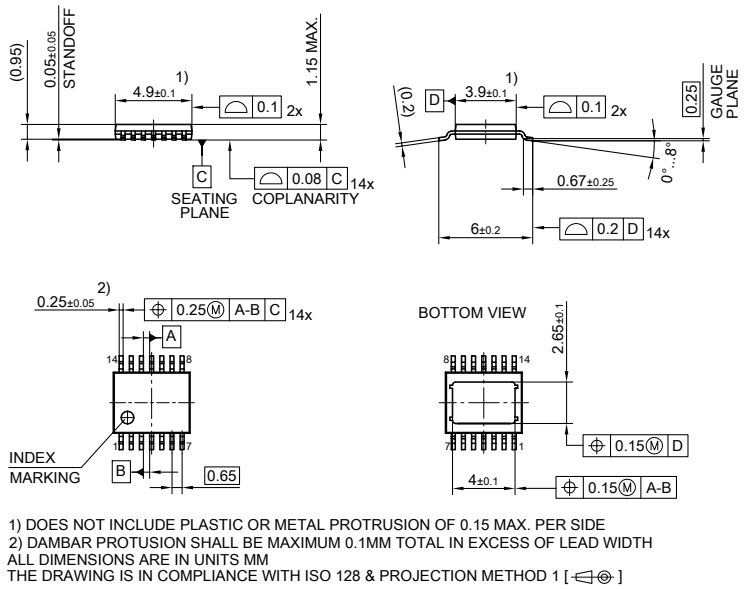


Figure 36 PG-TSDSO-14 (Thin (Slim) Dual Small Outline 14 pins) Package Outline

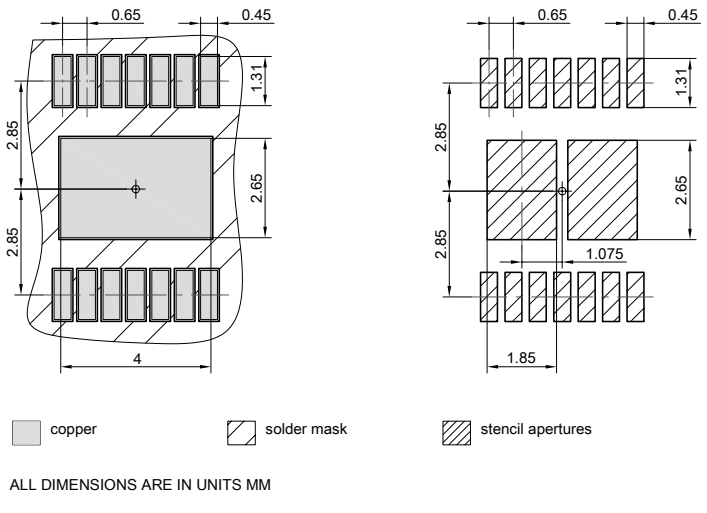


Figure 37 PG-TSDSO-14 (Thin (Slim) Dual Small Outline 14 pins) Package pads and stencil

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).

Further information on packages

https://www.infineon.com/packages

12 Revision History

Table 23 BTS7004-1EPR - List of changes

Revision	Changes
1.10, 2025-06-25	Update of datasheet template P_9.6.4.19 added P_9.6.4.20 added
1.00, 2023-09-12	Datasheet available

Trademarks

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