

# BTN7030-1EPA Power dissipation Application Note

## About this document

### Scope and purpose

This document compiles application hints for the application of the BTN7030-1EPA, the NovalithIC™ Lite. This document must be used in conjunction with the device datasheets.

### Intended audience

Developers, working with the BTN7030-1EPA.

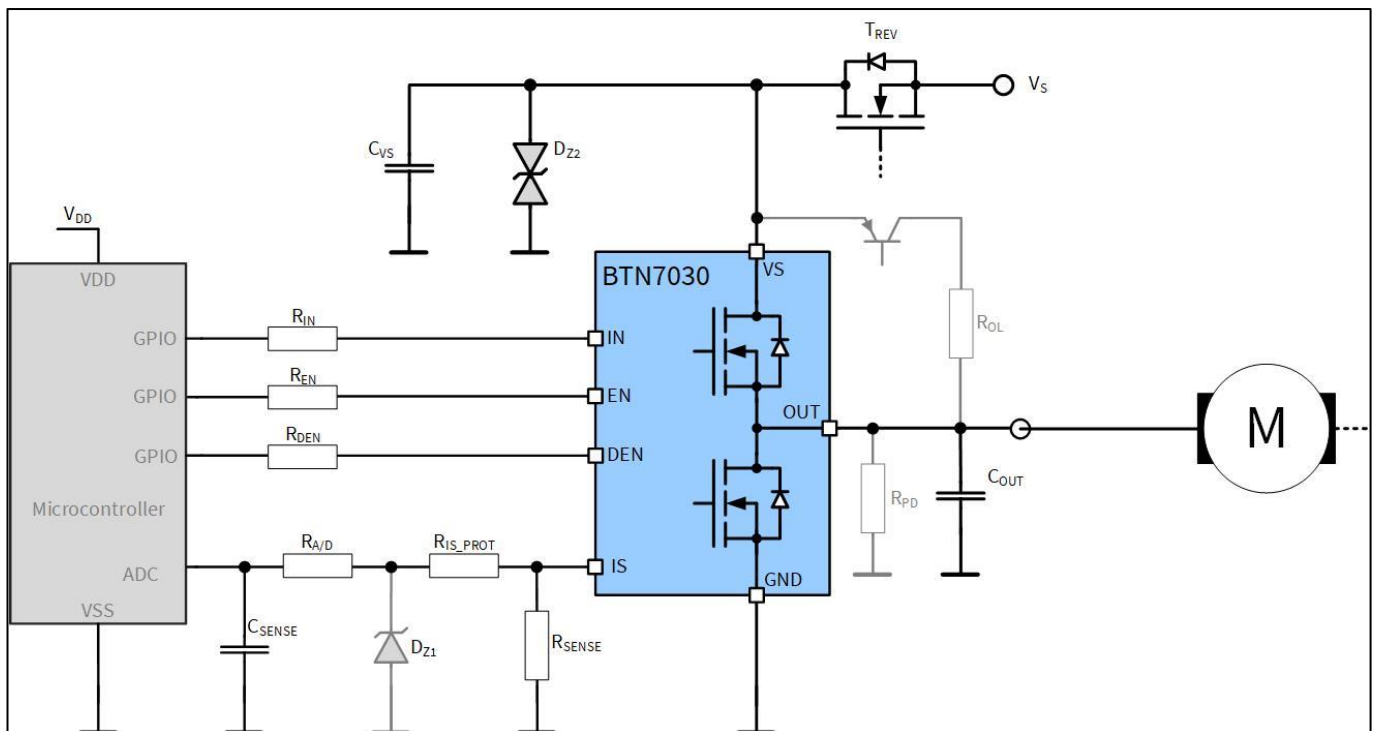
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## 1 Introduction

The NovalithIC™ Lite is part of an integrated half-bridge family, suitable for driving DC motors and solenoids.

The device is a monolithic chip integrated in SMART7 technology. BTN7030-1EPA is a protected half-bridge with integrated driver, providing protection and diagnosis functions. The high side power stage is built using a N-channel vertical power MOSFET with charge pump, while the low side power stage uses no charge pump. This device has an exposed pad which ensures better cooling capabilities.



**Figure 1** Application circuit example

## 2 Power dissipation

Power is dissipated in both the logic and in the individual MOSFETs of the device. The load currents in the MOSFETs generate most of the power dissipation. The following sections provide a basic method for calculating power dissipation in the MOSFET power stages to help the designer estimate overall power dissipation of the device. The power dissipation in the MOSFETs consists mainly of conducted losses and switching losses. Losses in the body diode only occur during the cross current protection phase.

### 2.1 Conduction / R<sub>DS(ON)</sub> power dissipation

In the ON-state, a MOSFET has a specific  $R_{ON}$  ( $R_{DS(ON)}$ ) which is listed in the data sheet. The  $R_{DS(ON)}$  is different for the high-side (HS) and the low-side (LS) MOSFETs. This means that  $R_{DS(ON)(LS/HS)}$  must be selected according to currently active power stage. A current flowing through this MOSFET generates the following conducted losses:

$$P_{RDS(ON)} = I_{OUT}^2 \cdot R_{DS(ON)(LS/HS)}$$

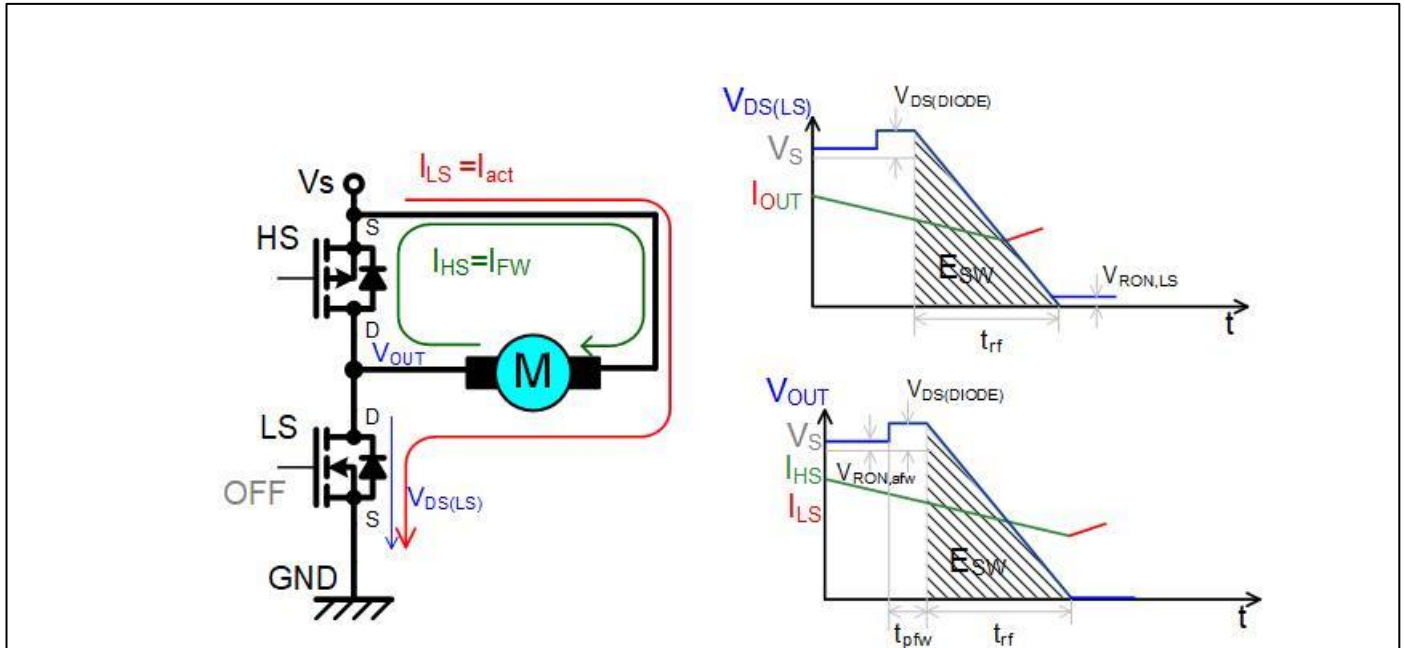
Equation 1

When the NovalithIC™ Lite is driven in a static condition, without PWM, the above equation can be used to estimate the static conduction losses for the high-side or low-side MOSFETs.

For static reverse current operation of the MOSFETs, the corresponding ON-state resistance values  $R_{DS(INV)(LS/HS)}$  are provided in the data sheet of the BTN7030-1EPA for both high-side and low-side switch.

### 2.2 Switching losses power dissipation

With PWM control, switching losses need to be considered because they generate most of the power dissipation for high PWM frequencies. As the NovalithIC™ Lite is designed to drive motors or other inductive loads, this chapter describes switching losses generated while driving an inductive load in PWM mode.



**Figure 2** Low-side switching scenario of BTN7030-1EPA

**Figure 2** shows low side PWM operation of a load connected to  $V_S$ . Current flows in the low side MOSFET when activated, and recirculates in the high side MOSFET when the low side MOSFET is OFF. During the time between the high side turning off and the low side turning on, current flows in the body diode of the high-side MOSFET. The motor winding inductance prevents instantaneous changes in current (per Lenz' rule), resulting in current flow in both the high-side body diode and low-side MOSFET during the switching period. While current flows in the high-side body diode the output voltage is fixed to  $V_{DS(DIODE)}$  above  $V_S$ . Once the low-side MOSFET supports the full load current, the output voltage decreases to  $I_{LS} * R_{DS(ON)}$ .

The rise- and fall- time shown in **Figure 2** is dependent on the supply voltage and can be estimated based on the switching ON/OFF slew rate  $dV/dt$ , which is given in the data sheet:

$$t_{rf} = t_{xS-ON/OFF} = \frac{V_S}{(dV/dt)_{xS-ON/OFF}}$$

**Equation 2**

The equation above can be used to perform calculations using the corresponding HS/LS data sheet parameters. The slew rate provided in the data sheet is for  $V_S = 18\text{ V}$ , representing the worst-case scenario.

Other assumptions, with a minor effect on the result, include the following:

- The load current during the switching process is constant.
- $V_{OUT}$  and  $V_{DS(HS)}$  have linear behavior.
- The switching times are assumed as equal and in the following always referred to as  $t_{rf}$ .

The switching energy  $E_{SW}$  is shown in **Figure 2**, and can be estimated using the equation below:

$$E_{SW} = \int_{t_{SL1}}^{t_{SL2}} V_S \cdot I_{OUT} dt = \frac{1}{2} \cdot V_S \cdot I_{OUT} \cdot t_{rf}$$

**Equation 3**

Using the formula for switching energy  $E_{SW}$  the average power loss  $P_{SW}$  can be determined by multiplying  $E_{SW}$  with two switching times per PWM period. This is shown here:

$$\overline{P_{SW}} = \frac{1}{2} \cdot V_S \cdot I_{OUT} \cdot t_{rf} \cdot 2 \cdot f_{PWM} = V_S \cdot I_{OUT} \cdot t_{rf} \cdot f_{PWM}$$

**Equation 4**

The NovalithIC™ Lite has a cross-current protection mechanism which ensures that an output MOSFET is turned ON only when the other one is OFF. This causes a freewheeling current through the MOSFET body diode  $V_{DS(DIODE)(XS)}$  before the resistive path is switched on. The power dissipation caused by the body diode can be calculated as follows:

$$P_{BD} = I_{OUT} \cdot V_{DS(DIODE)}$$

**Equation 5**

## 2.3 Entire power dissipation of the MOSFETs

The average power dissipation in PWM-mode consists of the switching losses plus the conducted losses. We must take into account that the losses occur in the high-side (HS) and low-side (LS) MOSFET. In the example where the motor is connected to VS, the switching losses occur in the low-side MOSFET. The conducted losses occur in the low-side MOSFET during the ON-phase and in the high-side MOSFET in the freewheeling phase, as shown in **Figure 2**. In PWM-mode, the PWM-period-time is:

$$T_{PWM} = \frac{1}{f_{PWM}}$$

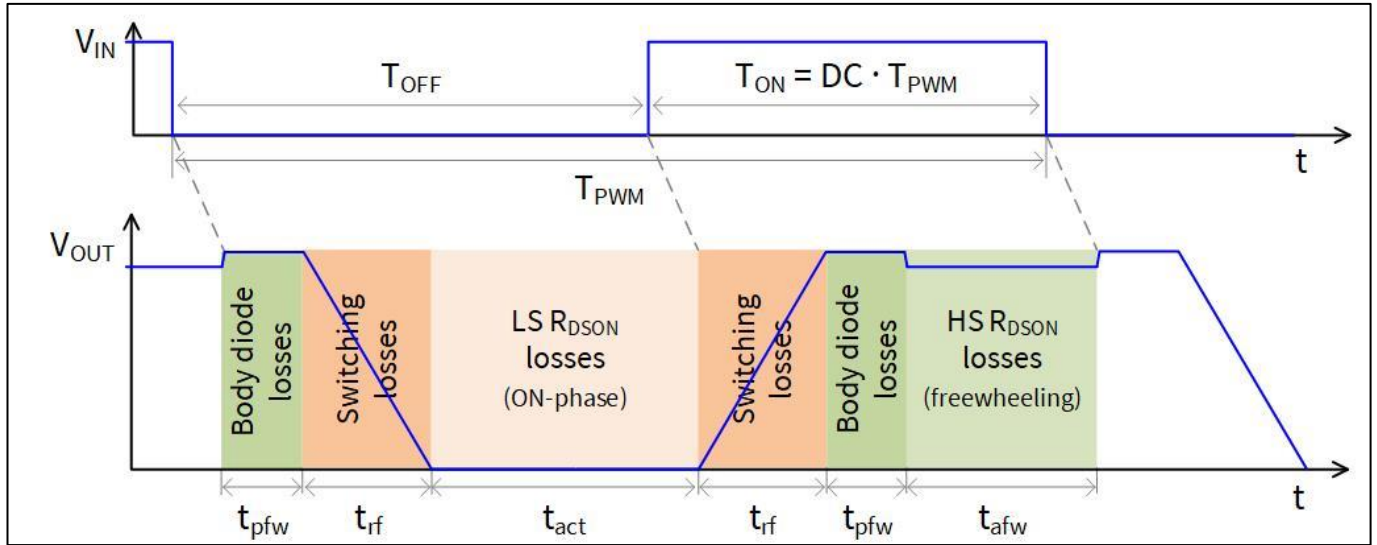
**Equation 6**

The duty cycle (DC) of the PWM-mode is the relation between the ON-time and the PWM-period-time defined as

$$DC = \frac{T_{ON}}{T_{PWM}}$$

**Equation 7**

All timings and occurring power dissipation sources for a motor-to-VS scenario is illustrated in **Figure 3** below.



**Figure 3 Entire power dissipation of BTN7030-1EPA with the motor connected to VS**

For the motor-to-VS scenario the resulting activation time of the actuator, the low-side MOSFET is:

$$T_{act} = T_{OFF} = T_{PWM} - T_{ON} = (1 - DC) \cdot T_{PWM}$$

**Equation 8**

## 2.4 Entire power dissipation in the actuator MOSFET

In the motor-to-GND scenario the active MOSFET is the high-side (HS) MOSFET and in motor-to-VS scenario, the active MOSFET is the low-side (LS) MOSFET, as shown in **Figure 2**. The entire power dissipation consists of two times the switching losses plus the conducted losses in the ON-phase, as shown in **Figure 3**. The time of the ON-phase in PWM-mode is provided by the following equation:

$$t_{act} = T_{OFF} - t_{pfw} - t_{rf}$$

**Equation 9**

This results in a total energy per PWM cycle for the actuator MOSFET, consisting of the switching and conduction /  $R_{DS(ON)}$  losses:

$$E_{act} = E_{SW} + E_{R_{DS(ON)}-LS} = V_S \cdot I_{OUT} \cdot t_{rf} + I_{OUT}^2 \cdot R_{DS(ON)(LS)} \cdot t_{act}$$

**Equation 10**

This results in an average power dissipation in the actuator MOSFET:

$$\overline{P_{act}} = E_{act} \cdot f_{PWM} = (V_S \cdot I_{OUT} \cdot t_{rf} + I_{OUT}^2 \cdot R_{DS(ON)(LS)} \cdot t_{act}) \cdot f_{PWM}$$

**Equation 11**

$\overline{P_{act}}$  is an estimation of the average power dissipation in the active MOSFET. In **Figure 2**, this is the low-side MOSFET for the motor-to-VS scenario.

## 2.5 Entire power dissipation in the freewheeling MOSFET

In the motor-to-VS scenario, the freewheeling MOSFET is the high-side MOSFET, as shown in **Figure 2**, and in the motor-to-GND scenario, the freewheeling MOSFET is the low-side MOSFET. The entire power dissipation consists of the conduction /  $R_{DS(ON)}$  losses in the freewheeling phase and twice the passive freewheeling losses. The passive freewheeling losses calculate as follows:

$$E_{pfw} = V_{DS(DIODE)(LS)} \cdot I_{OUT} \cdot t_{pfw}$$

**Equation 11**

The body diode voltage for the both high-side and low-side MOSFETs  $V_{DS(DIODE)(XS)}$  can be found in the data sheet. For the durations of the passive freewheeling, the blank time between switches activation, also provided in the datasheet can be used:

$$t_{pfw} = t_{BLANK(xS-xS)}$$

**Equation 12**

The duration of the active freewheeling phase in PWM-mode is provided by the equation below:

$$t_{afw} = T_{ON} - t_{rf} - t_{pfw} = DC \cdot T_{PWM} - t_{rf} - t_{pfw}$$

**Equation 13**

The equation to determine the energy generated during the active freewheeling in the corresponding freewheeling MOSFET together with the dedicated ON-state resistance for inverse currents:

$$E_{afw} = I_{OUT}^2 \cdot R_{DS(INV)(HS)} \cdot t_{afw}$$

**Equation 14**

From the two energy equations above, the average power dissipation in the freewheeling MOSFET can be determined by multiplying the sum by  $f_{PWM}$ :

$$\overline{P_{fw}} = (2 \cdot E_{pfw} + E_{afw}) \cdot f_{PWM} = I_{OUT} \cdot (2 \cdot V_{DS(DIODE)(LS)} \cdot t_{pfw} + I_{OUT} \cdot R_{DS(ON)(HS)} \cdot t_{afw}) \cdot f_{PWM}$$

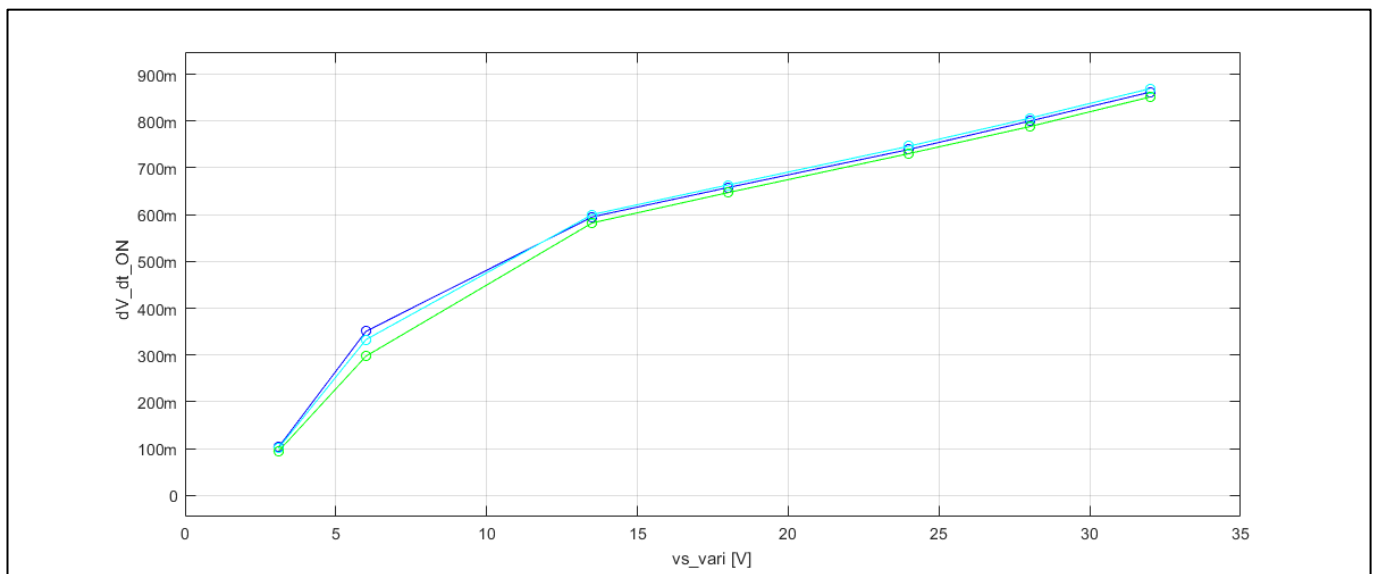
**Equation 15**

This is an estimation of the average power dissipation in the freewheeling MOSFET. In **Figure 2**, this is the high-side MOSFET for the load-to-VS scenario.

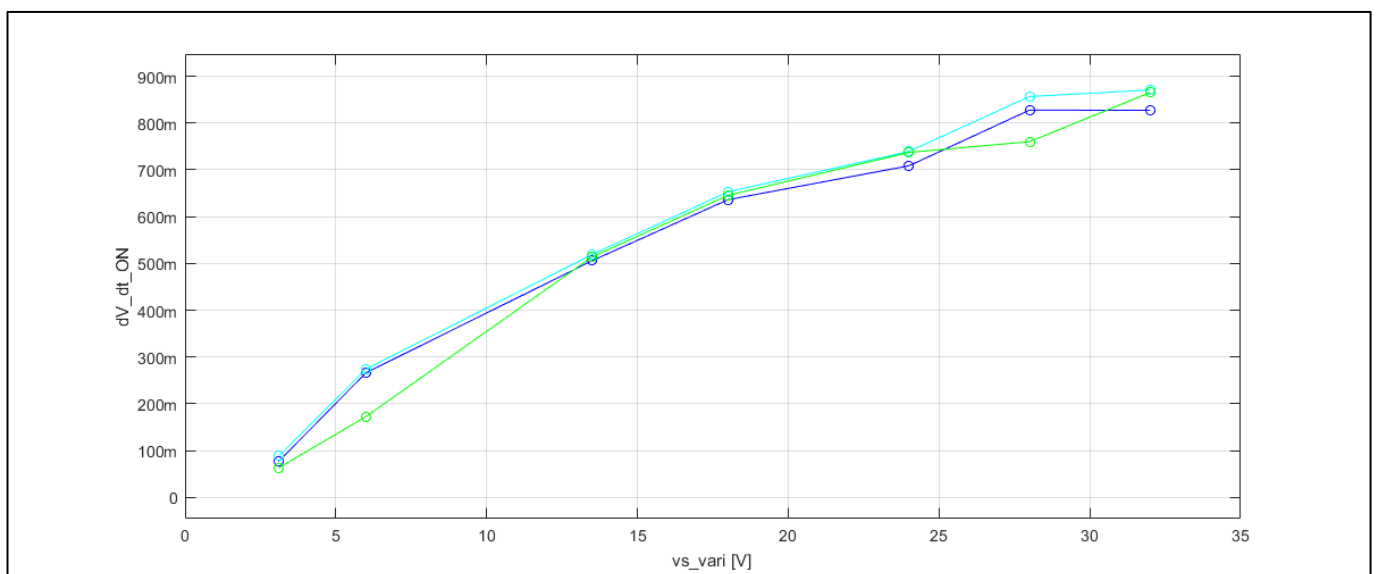
## 2.6 Slew rate dependency on the supply voltage

In the motor-to-GND scenario the active MOSFET is the high-side (HS) MOSFET and in motor-to-VS scenario, the active MOSFET is the low-side (LS) MOSFET, as shown in **Figure 2**.

While in the datasheet the value is provided for  $V_S = 18\text{ V}$ , the slew rate  $dV/dt$  has different values depending on  $V_S$  and junction temperature. The typical switch-on slew rate for LS and HS stages are presented in **Figure 4** and **Figure 5** in V/ms.



**Figure 4** Typical switch-on slew rate LS dependency on the supply voltage  $V_S$



**Figure 5** Typical switch-on slew rate HS dependency on the supply voltage  $V_S$



### 3 Summary – Power dissipation in a nutshell

An overview of necessary steps to estimate the power dissipation for the load-to-VS scenario is summarized in the following table.

#### 3.1 Load to VS

Table 1 Summary power dissipation load to VS

	Load to VS (high-side freewheeling)
Timing diagram	
Application parameters	<ul style="list-style-type: none"> <li>Supply voltage: <math>V_S</math></li> <li>Load current: <math>I_{OUT}</math></li> <li>PWM frequency: <math>f_{PWM}</math></li> <li>PWM Duty-cycle: <math>DC</math></li> </ul>
BTN7030-1EPA Data sheet parameters	<ul style="list-style-type: none"> <li>Switch ON/OFF slew rate: <math>(dV/dt)_{XS-ONOFF}</math></li> <li>ON-state resistance, low-side: <math>R_{DS(ON)(LS)}</math></li> <li>ON-state resistance, high-side switch: <math>R_{DS(INV)(HS)}</math></li> <li>Blank time between switches activation HS to LS: <math>t_{BLANK(HS-LS)}</math></li> </ul>
Timings	<ol style="list-style-type: none"> <li><math>t_{rf} = \frac{V_S}{(dV/dt)_{XS-ONOFF}}</math></li> <li><math>t_{pfw} = t_{BLANK(HS-LS)}</math></li> <li><math>T_{PWM} = \frac{1}{f_{PWM}}</math></li> <li><math>T_{ON} = DC \cdot T_{PWM}</math></li> <li><math>T_{OFF} = T_{PWM} - T_{ON}</math></li> <li><math>t_{act} = T_{OFF} - t_{pfw} - t_{rf}</math></li> <li><math>t_{afw} = T_{ON} - t_{rf} - t_{pfw} = DC \cdot T_{PWM} - t_{rf} - t_{pfw}</math></li> </ol>
Low-side losses	<ol style="list-style-type: none"> <li>Average switching losses:  <math display="block">\overline{P_{SW}} = V_S \cdot I_{OUT} \cdot t_{rf} \cdot f_{PWM}</math> </li> </ol>

	<p><b>Load to VS</b> (high-side freewheeling)</p>
	<p>2. Average conduction / <math>R_{DS(ON)}</math> losses:  <math display="block">\overline{P_{R_{DS(ON)}-LS}} = (I_{OUT}^2 \cdot R_{DS(ON)(LS)} \cdot t_{act}) \cdot f_{PWM}</math></p> <p>3. Total average losses low-side:  <math display="block">\overline{P_{LS}} = \overline{P_{SW}} + \overline{P_{R_{DS(ON)}-LS}}</math></p>
<b>High-side losses</b>	<p>1. Passive FW – average body-diode freewheeling losses:  <math display="block">\overline{P_{pfw}} = 2 \cdot V_{DS(DIODE)(HS)} \cdot I_{OUT} \cdot t_{pfw} \cdot f_{PWM}</math></p> <p>2. Active FW – average conduction / <math>R_{DS(ON)}</math> losses:  <math display="block">\overline{P_{afw}} = I_{OUT}^2 \cdot R_{DS(INV)(HS)} \cdot t_{afw} \cdot f_{PWM}</math></p> <p>3. Total average losses high-side:  <math display="block">\overline{P_{HS}} = \overline{P_{pfw}} + \overline{P_{afw}}</math></p>

### 3.2 Load to GND

Table 2 Summary power dissipation load to GND

	<p><b>Load to GND</b> (low-side freewheeling)</p>
<b>Timing diagram</b>	
<b>Application parameters</b>	<ul style="list-style-type: none"> <li>Supply voltage: <math>V_S</math></li> <li>Load current: <math>I_{OUT}</math></li> <li>PWM frequency: <math>f_{PWM}</math></li> <li>PWM Duty-cycle: <math>DC</math></li> </ul>
<b>BTN7030-1EPA Data sheet parameters</b>	<ul style="list-style-type: none"> <li>Switch ON/OFF slew rate: <math>(dV/dt)_{XS-ONOFF}</math></li> <li>ON-state resistance, low-side: <math>R_{DS(ON)(LS)}</math></li> <li>ON-state resistance, high-side switch: <math>R_{DS(INV)(HS)}</math></li> <li>Blank time between switches activation LS to HS: <math>t_{BLANK(LS-HS)}</math></li> </ul>
<b>Timings</b>	<ol style="list-style-type: none"> <li><math display="block">t_{rf} = \frac{V_S}{(dV/dt)_{XS-ONOFF}}</math></li> <li><math display="block">t_{pfw} = t_{BLANK(LS-HS)}</math></li> </ol>

	<b>Load to GND</b> (low-side freewheeling)
	$3. \quad T_{PWM} = \frac{1}{f_{PWM}}$ $4. \quad T_{ON} = DC \cdot T_{PWM}$ $5. \quad T_{OFF} = T_{PWM} - T_{ON}$ $6. \quad t_{act} = T_{ON} - t_{p_{fw}} - t_{rf}$ $7. \quad t_{afw} = T_{OFF} - t_{rf} - t_{p_{fw}} = DC \cdot T_{PWM} - t_{rf} - t_{p_{fw}}$
	8.
<b>Low-side losses</b>	$1. \quad \text{Passive FW - average body-diode freewheeling losses:}$ $\overline{P_{p_{fw}}} = 2 \cdot V_{DS(DIODE)(LS)} \cdot I_{OUT} \cdot t_{p_{fw}} \cdot f_{PWM}$ $2. \quad \text{Active FW - average conduction / } R_{DS(ON)} \text{ losses:}$ $\overline{P_{afw}} = I_{OUT}^2 \cdot R_{DS(INV)(LS)} \cdot t_{afw} \cdot f_{PWM}$ $3. \quad \text{Total average losses low-side:}$ $\overline{P_{LS}} = \overline{P_{p_{fw}}} + \overline{P_{afw}}$
<b>High-side losses</b>	$1. \quad \text{Average switching losses:}$ $\overline{P_{SW}} = V_S \cdot I_{OUT} \cdot t_{rf} \cdot f_{PWM}$ $2. \quad \text{Average conduction / } R_{DS(ON)} \text{ losses:}$ $\overline{P_{RDS(ON)-HS}} = (I_{OUT}^2 \cdot R_{DS(ON)(HS)} \cdot t_{act}) \cdot f_{PWM}$ $3. \quad \text{Total average losses high-side:}$ $\overline{P_{HS}} = \overline{P_{SW}} + \overline{P_{RDS(ON)-HS}}$

### 3.3 Switching of resistive loads

In the data sheet the typical energy dissipated for an output voltage transition between 10% and 90% for one single ON or OFF switching event is provided with  $E_{ON(xS)}$  or  $E_{OFF(xS)}$  for an **resistive load** for both the high-side (HS) and low-side (LS) MOSFET.

The value in the datasheet is valid for the default testing load of  $R_{load} = 3.3 \, \Omega$  with a negligible inductance. This results in a static current after full switching on of the MOSFET:

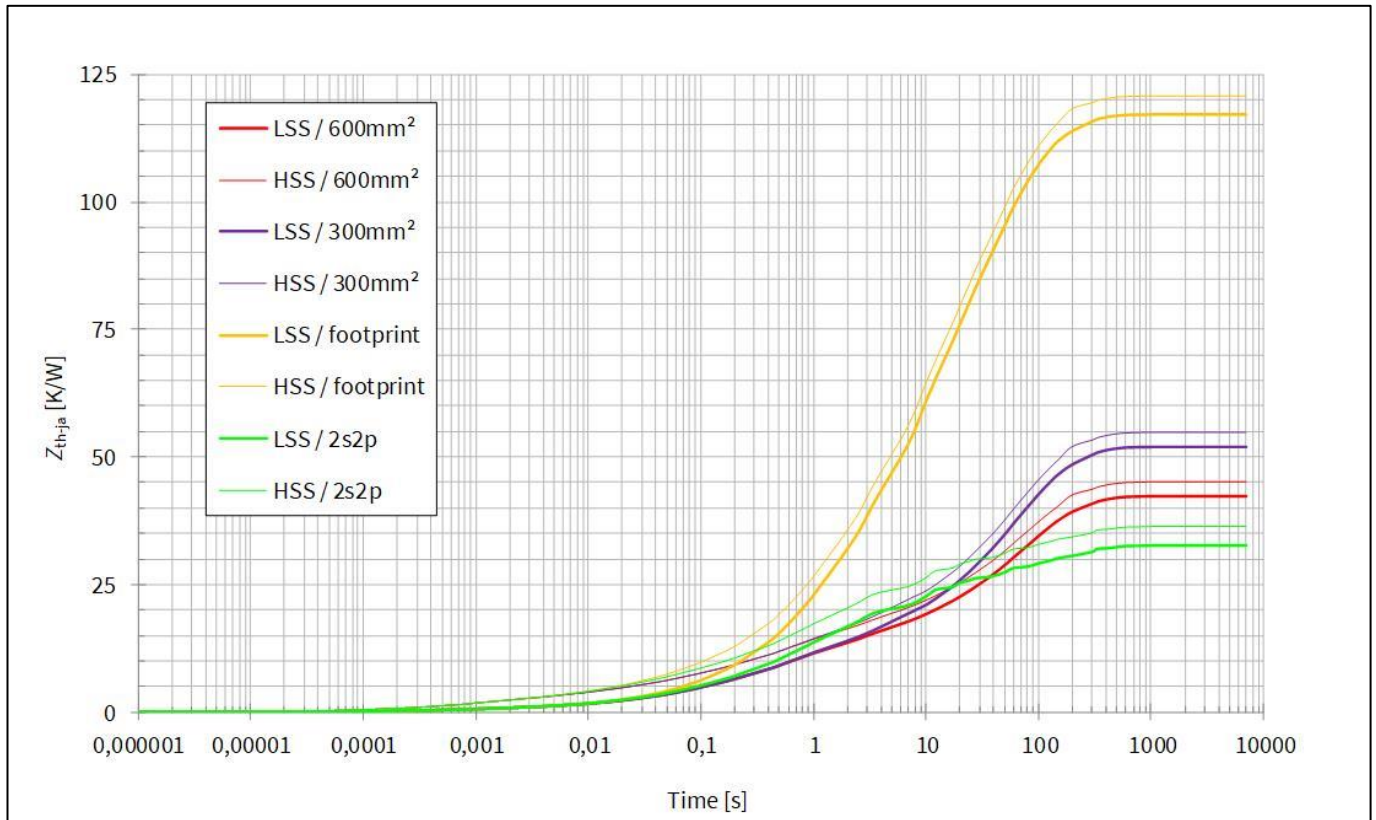
$$I_{OUT} = \frac{VS}{R_{load}} = \frac{13.5V}{3.3 \, \Omega} = 4.09 \, A$$

**Equation 16**

For the switch ON energy measurement, the load current increases from 0 A linear with the output voltage until the steady state current of 4.09 A. While for the switch OFF voltage the current decreases from the steady state down to 0 A.

## 4 Thermal performance

The parameters  $R_{thJA(LS/HS)}$  (thermal resistance junction to ambient) and  $R_{thJC}$  (thermal resistance junction to case) are important for the package. The necessary cooling area can be estimated based on these values, which is important for the design. In order to ensure comparability, these values are specified assuming a setup according to JEDEC JESD51-2,-5,-7 placing the device on FR4 1s0p or 2s2p board at natural convection, with an ambient temperature  $T_a = 85^\circ\text{C}$  and a given power  $P = 1\text{ W}$ .



**Figure 6 Typical thermal impedance for  $T_{ambient} = 85^\circ\text{C}$ ; Simulation with 1 W of power dissipation**

Typical values for junction to ambient thermal resistance are:

- HSS: typ = 36 K/W
- LSS: typ = 32.5 K/W

## 5 Revision history

Document version	Date of release	Description of changes
1.2	2021-01-20	Fixed Figure 2, 4, 5
1.1	2020-11-24	Chapter Introduction updated
1.0	2020-08-28	First release

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