PROFET™+2 12V

Grade0 nominal current calculation

About this document

Scope and purpose

This document shows how to calculate the nominal current for a device of the PROFET™+2 12V family, with focus on the Grade0 qualified parts.

Intended audience

Engineers, hobbyists and students who want to understand protected high-side switches for transmission applications with extended or/and high temperature mission profiles, *under the hood* applications requiring an extended junction temperature range up to 175°C and powertrain systems such as transmission applications.

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1 Introduction

PROFET™+2 12V is the latest generation of smart high-side switches for automotive and industrial applications based on SMART7 technology. The family offers single, dual and four channel devices (from 2 mΩ to 200 mΩ) in PG-TSDSO-14 exposed pad package and provides state-of-the-art diagnostics and protection features.

The family provides outstanding energy efficiency with reduced current consumption, state-of-the-art current sense accuracy (k_{ILIS}) and low cranking voltage capability.

The PROFET™+2 12V Grade0 portfolio (see **Table 1**) consists of six different high-side switches (from 4 mΩ to 80 mΩ. It offers an extended junction temperature range up to 175°C, which allows partitioning at high ambient temperatures with higher ohmic parts.

Due to the AEC-Q100 Grade0 qualification, the PROFET™+2 12V Grade0 portfolio is able to perform extended life cycles at elevated temperatures.

Table 1 Product overview

Product	$R_{DS(ON)}$ typ @ 25°C	$R_{DS(ON)}$ max @ 175°C	Target Load Current[1]	Protection and Diagnosis
BTS7004-1EPZ	1 x 4.4 mΩ	1 x 8.8 mΩ	15 A	**Intelligent Latch** same as BTS7004-1EPP k_{ILIS}: 20,000
BTS7006-1EPZ	1 x 6.6 mΩ	1 x 13 mΩ	13 A	**Intelligent Latch** same as BTS7006-1EPP k_{ILIS}: 17,700
BTS7008-1EPZ	1 x 9 mΩ	1 x 18 mΩ	10 A	**Intelligent Restart Control** k_{ILIS}: 9500 (*BTS7008-1EPA* → k_{ILIS}: 5500)
BTS7008-2EPZ	2 x 9 mΩ	2 x 18 mΩ	8 A	**Intelligent Restart Control** k_{ILIS}: 9500 (*BTS7008-2EPA* → k_{ILIS}: 5500)
BTS7040-1EPZ	1 x 19 mΩ	1 x 39 mΩ	5 A	**Intelligent Restart Control** k_{ILIS}: 3000 (*BTS7040-1EPA* → k_{ILIS}: 1800)
BTS7080-2EPZ	2 x 20.9 mΩ	2 x 43 mΩ	3 A	**Intelligent Restart Control** k_{ILIS}: 3000 (*BTS7080-2EPA* → k_{ILIS}: 1800)

1 According to Jedec JESD51-2,-5,-7 at natural convection on FR4 2s2p board, T_A = 85°C

2 Nominal current calculation

In this chapter the formulas used to calculate the nominal current for a PROFET™+2 12V product are shown.

The calculations are based on a Grade0 device that is mounted on a FR4 PCB as well as on a HiT PCB. The FR4 PCB withstands maximum temperatures of 135°C, the HiT PCB withstands temperatures of 170°C. The maximum junction temperature of a Grade1 device is 150°C, while it is 175°C for a Grade0 device. The following formulas are derived by considering the limits of PCB and junction temperature.

The maximum power dissipation allowed by an exposed pad package without damage of the PCB is:

$$P_{\mathrm{DISS}} = \frac{T_{J(\mathrm{ABS}),\,\mathrm{MIN}} - T_A}{R_{\mathrm{thJA}}} \quad (1)$$

where:

- $T_{J(ABS),MIN}$ = minimum thermal shutdown temperature (absolute), see in datasheet chapter 8.6, parameter P_8.6.0.1
- T_A = ambient temperature
- R_{thJA} = package thermal resistance "junction to ambient", see in datasheet chapter 4.4, parameter P_4.4.0.4

This power needs to be compared to the maximum power dissipation allowed by the module design rules ($P_{DISS,PKG}$). However, no precise values for $P_{DISS,PKG}$ are specified. Therefore it is assumed that a package like PG-TSDSO-14 (as used for SMART7 PROFET™+2 12V devices) allows a maximum power dissipation of 1.1 W. In the figures included in this Application Note $P_{DISS,PKG}$ is equal to 1.1 W unless otherwise specified.

$$P_{\mathrm{DISS,\,MAX}} = \min\left(P_{\mathrm{DISS}}; P_{\mathrm{DISS,\,PKG}}\right) \quad (2)$$

When the maximum power is dissipated, the maximum temperature allowed by the PCB (T_{CASE}) is calculated by taking the minimum between the maximum PCB temperature (135°C for FR4 PCB, 170°C for HiT PCB) and the temperature reached by the package:

$$T_{\mathrm{CASE}} = \min\left(T_{\mathrm{PCB,\,MAX}}; T_A + P_{\mathrm{DISS,\,MAX}} \cdot \left(R_{\mathrm{thJA}} - R_{\mathrm{thJC,\,TYP}}\right)\right) \quad (3)$$

where:

- $T_{PCB,MAX}$ = maximum temperature allowed by the PCB
- $R_{thJC,TYP}$ = typical package thermal resistance "junction to soldering point" (the exposed pad is considered as "soldering point" and equivalent to the PCB), see in datasheet chapter 4.4, parameter P_4.4.0.2

When the PCB temperature is T_{CASE}, the power dissipation is:

$$P_{\mathrm{DISS}}(T_{\mathrm{CASE}}) = \frac{T_{\mathrm{CASE}} - T_A}{R_{\mathrm{thJA}} - R_{\mathrm{thJC,\,TYP}}} \quad (4)$$

When the power described in the previous formulas is dissipated, then the maximum junction temperature $T_{JUNCTION}$ is calculated by taking the minimum between the minimum thermal shutdown temperature (150°C for Grade1 devices, 175°C for Grade0 devices) and the temperature reached by the PCB:

$$T_{\mathrm{JUNCTION}} = \min\left(T_{J(\mathrm{ABS}),\,\mathrm{MIN}}; T_{\mathrm{CASE}} + P_{\mathrm{DISS,\,MAX}} \cdot R_{\mathrm{thJC,\,TYP}}\right) \quad (5)$$

2 Nominal current calculation

At this point the $R_{DS(ON)}$ as function of the maximum junction temperature $T_{JUNCTION}$ can be calculated using:

$$R_{DS(ON)}(T_{JUNCTION}) = \frac{R_{DS(ON),MAX}}{1+\frac{(k_{TECH}-1)\cdot(150-T_{JUNCTION})}{125}} \tag{6}$$

where:

- $R_{DS(ON),MAX}$ = maximum channel $R_{DS(ON)}$ at 150°C, see in datasheet chapter 7.5.1, parameter P_7.5.x.2
- k_{TECH} = technology coefficient-ratio between maximum channel $R_{DS(ON)}$ at 150°C and maximum channel $R_{DS(ON)}$ at 25°C

When the junction temperature is $T_{JUNCTION}$, the power dissipation is:

$$P_{DISS}(T_{JUNCTION}) = \frac{T_{JUNCTION}-T_A}{R_{thJA}} \tag{7}$$

Finally, the typical value of the nominal current $I_{L(NOM)}$ is:

$$I_{L(NOM)}(P_{DISS}; T_{JUNCTION}) = \sqrt{\frac{P_{DISS}(T_{JUNCTION})}{n_{CH}\cdot R_{DS(ON)}(T_{JUNCTION})}} \tag{8}$$

where:

- n_{CH} = number of channels of the device (assuming that all channels dissipate the same fraction of the total allowed power dissipation)

3 Examples

In this chapter examples for a standard temperature scenario and for high temperature scenarios are shown.

3.1 Standard temperature scenario

- $T_{PCB,MAX}$ = 150°C
- BTS7004-1EPP: $T_{J(ABS),MIN}$ = 150°C
- BTS7004-1EPZ: $T_{J(ABS),MIN}$ = 175°C

In the figure below the nominal current $I_{L(NOM)}$varying the ambient temperature T_A is shown:

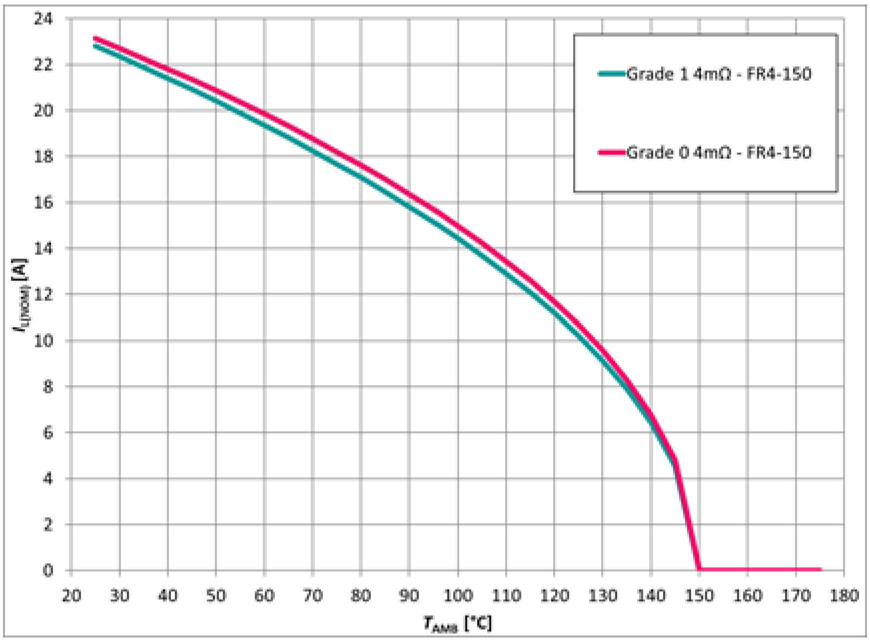

Figure 1 **Standard temperature scenario**

It is important to notice that the Grade1 qualified product BTS7004-1EPP and the Grade0 qualified product BTS7004-1EPZ have the same current capabilities since they have the same $R_{DS(ON)}$. In this example the limiting factor for the current is the maximum temperature of the PCB.

3.2 High temperature scenario 1

- $T_{PCB,MAX}$ = 170°C
- BTS7004-1EPP: $T_{J(ABS),MIN}$ = 150°C
- BTS7004-1EPZ: $T_{J(ABS),MIN}$ = 175°C

In the figure below the nominal current $I_{L(NOM)}$ varying the ambient temperature T_A is shown:

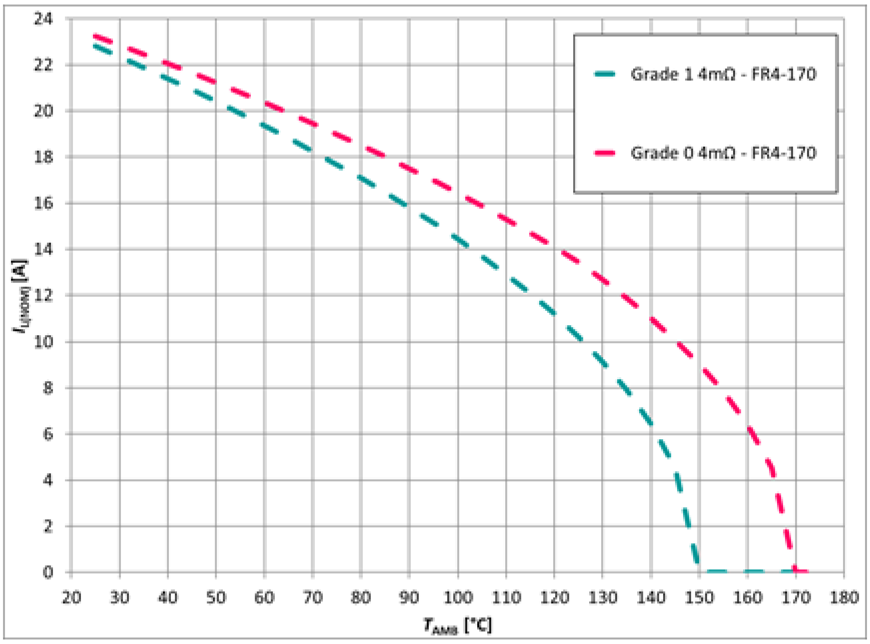

Figure 2 **High temperature scenario 1**

In this example the load current capability of the Grade1 qualified product BTS7004-1EPP is limited by the minimum thermal shutdown temperature (150°C). The Grade0 qualified product BTS7004-1EPZ is able to drive current until the maximum PCB temperature is reached (170°C).

3.3 High temperature scenario 2

- $T_{PCB,MAX}$ = 170°C
- BTS7004-1EPP: $T_{J(ABS),MIN}$ = 150°C
- BTS7004-1EPZ: $T_{J(ABS),MIN}$ = 175°C
- BTS7008-1EPZ: $T_{J(ABS),MIN}$ = 175°C

In the figure below the nominal current $IL_{(NOM)}$ varying the ambient temperature T_A is shown:

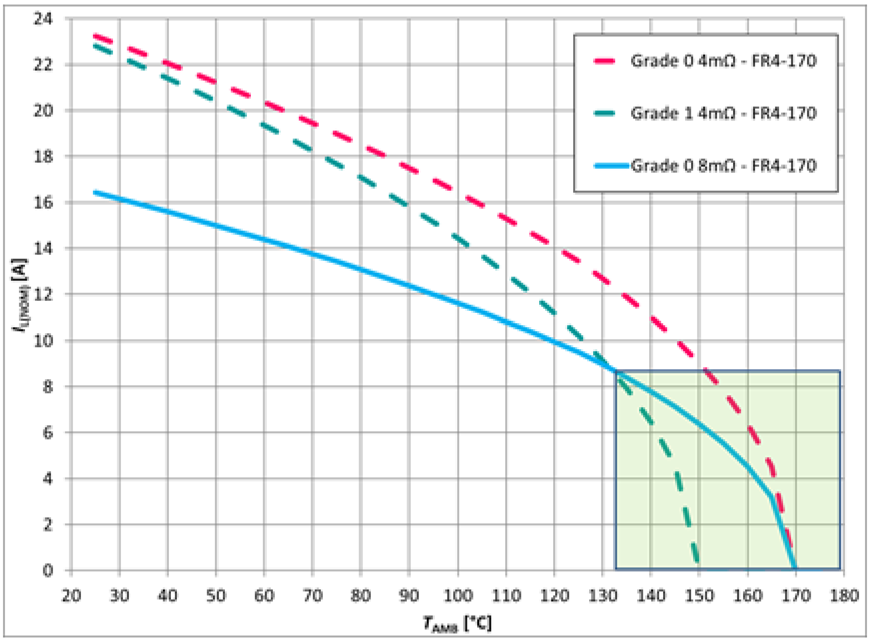

Figure 3 **High temperature scenario 2**

In this example the Grade0 qualified product BTS7008-1EPZ is also considered. It is important to notice that the higher ohmic product Grade0 qualified BTS7008-1EPZ (blue line) is able to drive more current than the Grade1 qualified BTS7004-1EPP at higher temperatures.

4 Conclusion

The calculation of the nominal current for Grade0 devices should take into account many parameters. The focus is on:

- The maximum temperature allowed by the device (before switching off due to overtemperature)
- The maximum temperature allowed by the PCB

As a result of the extended thermal budget, a Grade0 qualified device can withstand higher currents at higher ambient temperatures, even with a higher $R_{DS(ON)}$. It means that partitioning with higher ohmic parts at high ambient temperatures is enabled, leading to cost savings.

5 Revision history

Table 2 Revision History

Document version	Date of release	Changes
v01_00	2020-08-06	Initial version

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