Automotive Power Semiconductors

Application Note

Short circuit behaviour of the Speed TEMPFET® family

by Benno Koeppl, Jürgen Kositza, Christian Arndt and Jean-Philippe Boeschlin

1. Introduction

The era of the Infineon's Smart Power Low Side switches began with the introduction of the TEMPFET®.
TEMPFET® devices are temperature protected FET-switches. They can be controlled as any discrete FET, but in addition they implement a temperature protection.
Characteristic for TEMPFET® devices is the temperature sensor. This sensor is mounted on top of a standard MOSFET. Although it is electrically isolated to the discrete FET, it is thermally well coupled. This concept enables the sensor to measure the real junction temperature of the MOSFET and hence to protect the FET against overtemperature.
The temperature sensor has the behaviour of a thyristor. It fires at overtemperature.
In the classic version of the TEMPFET®, the temperature sensor is connected already internally in-between gate and source of the MOSFET. In case of an overtemperature it simply shorts gate and source and hence switches the MOSFET off. Since this concept requires a serial gate resistor of about 3kOhm in order to protect the internal thyristor, the classic TEMPFET® devices are restricted to applications with slower switching times.
With the new Speed-TEMPFET® family the temperature sensor is externally available. This enables the user of a Speed TEMPFET® on the one hand side to define, how the Speed TEMPFET® should react at overtemperature, on the other hand it extends the application area for temperature protected FET switches towards fast-switching PWM applications.
To ensure short circuit protection for classic TEMPEFT® devices, the maximum gate to source voltage has to be limited. Individual voltage values for short circuit protection are given in the TEMPFET® datasheet.
For the Speed-TEMPFET family this information is not given in the data sheets. Therefore this application note will give a more detailed information, how short circuit protection of Speed-TEMPFET® devices can be achieved.

2. The short circuit protection of TEMPFET® devices

2.1. The structure of a TEMPFET®

Both, TEMPFET® and Speed-TEMPFET® have the same basic superstructure.
In general a standard MOSFET serves as a power stage and is used as a base chip. Another small chip serves as temperature sensor and is mounted on top of the MOSFET base chip (Fig. 1).

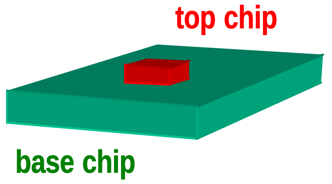


Fig. 1: basic superstructure of the TEMPFET ®

The temperature sensor can be understood as a thyristor. It is non conductive at normal temperatures but becomes conductive at overtemperatures.
In the event of an overtemperature the sensor simply shorts the gate and the source of a classic TEMPFET® and therefore switches the TEMPFET® off. In the case of a Speed TEMPFET® the digital overtemperature signal will be available for further processing at two output pins. Overtemperature will not explicitly lead to a switch off of the Speed TEMPFET®, unless the external connection is realised in the necessary way.
A detailed description of this overtemperature functionality is given in the application note „Temperature protection concept – Speed TEMPFET®".

2.2. Short circuit protection of classic TEMPFET® devices

In general short circuit protection of the TEMPFET® is based on overtemperature detection.
In the event of a short circuit, the MOSFET consumes most of the power supply voltage. The short circuit current that flows is usually limited by the transfer characteristic of the MOSFET. Therefore the overall power dissipation in the MOSFET is very high. This leads to a rapid rise of the base chip temperature. The temperature of the sensor follows this rapid rise with a small delay due the thermal capacitance of the top chip.
In order to limit the maximum power dissipation during a short circuit and hence enable the top chip temperature to follow the base chip temperature in time, the gate source voltage of the TEMPFET® has to be limited via an external Zener diode (ZD1 in figure 2).

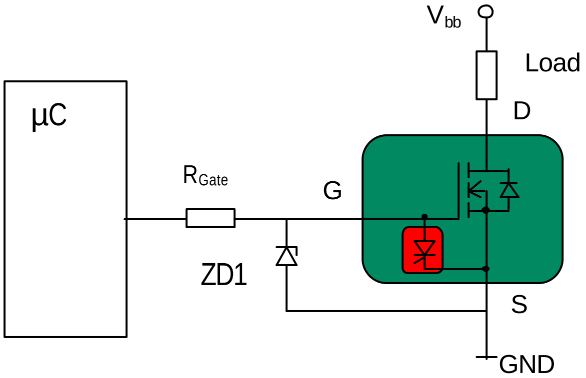


Fig. 2: External wiring of a Classic TEMPFET®

If the short circuit current had not been limited via the gate voltage, such high power losses would have occurred in the base chip that in worst case situations the top chip would not have responded fast enough. This might eventually result in an already thermally destroyed base chip before the temperature sensor is even able to sense overtemperature.
In order to ensure full short circuit protection of the classic TEMPFET® devices the maximum gate voltage has to be limited. Two diagrams provide the required information in the data sheets. „Short-circuit protection“ and „Max. gate voltage“.
The „Max. gate voltage“ diagram shows the maximum allowed gate voltage over the maximum drain source voltage were short circuit protection is ensured. This value is the voltage rating of the Zener diode ZD1 to be implemented.

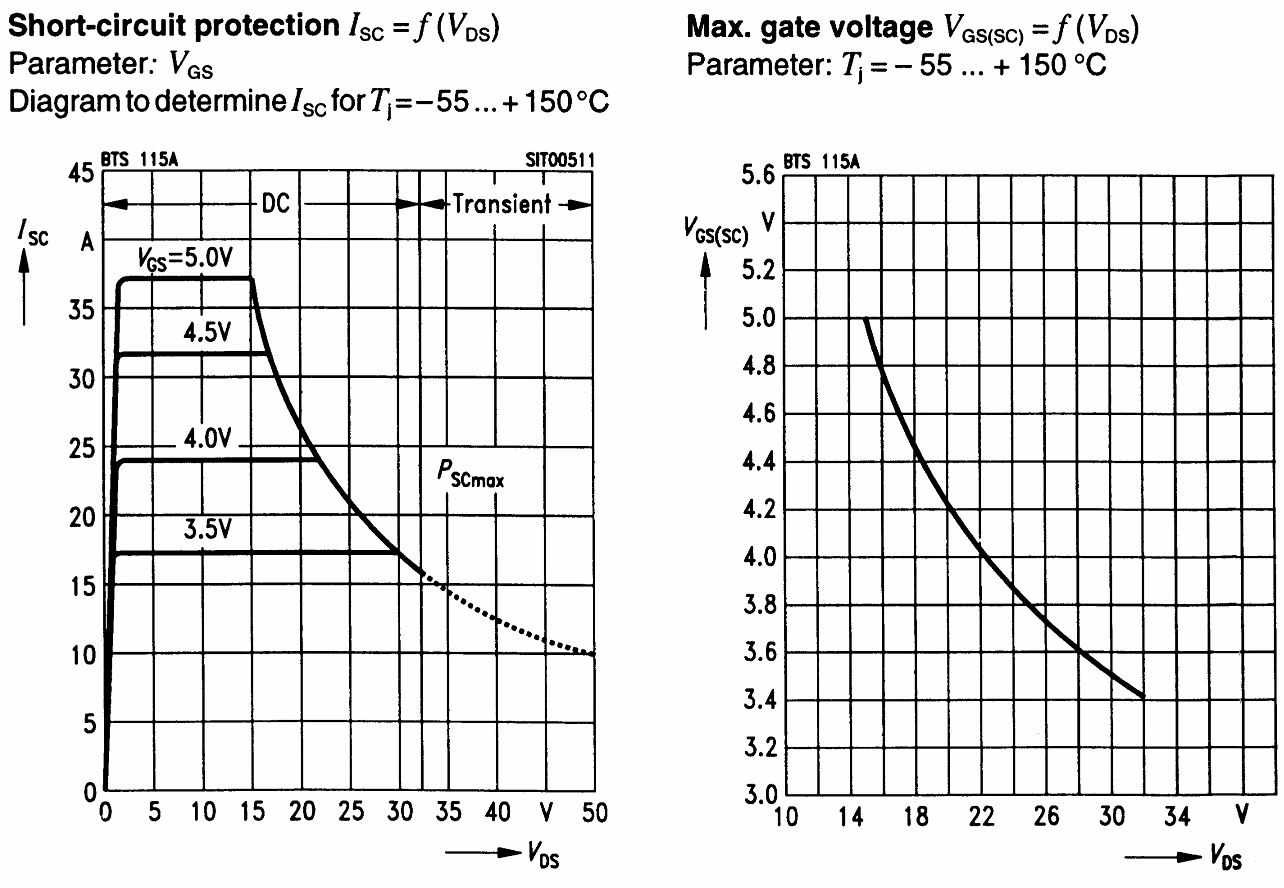


Figure 3: Example „Short circuit protection“ and „Max. gate voltage“ diagram

The output characteristic of the MOSFET is specified in the „Short circuit protection“ diagram. The diagram shows the drain current in the event of a short circuit depending on the drain source voltage and the applied gate voltage.
Since the drain current has its maximum values at low temperatures, the illustrated graph applies for the minimum temperature (here –55°C).

2.3. Short circuit detection of Speed-TEMPFET® devices

As with the TEMPFET® devices short circuit detection for Speed TEMPFET® devices is based on overtemperature detection. To achieve short circuit detection and protection the temperature sensor has to be monitored.
On account of the Speed TEMPFET® concept it is necessary for the user to switch off the TEMPFET within 1 ms after receiving the overtemperature signal.
Speed TEMPFET® devices are in general not self-protective. Short circuit protection has to be realised by the external circuitry and logic. A typical application is shown in fig. 4

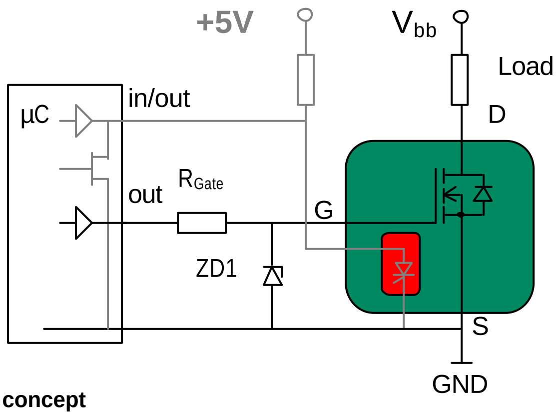


Fig. 4: Speed-TEMPFET concept

Speed TEMPFET® devices use for D-Mos power stage the technology S-FET. Since the $R_{DS(on)}$ is much lower compared to the technology used in classic TEMPFET® devices much higher current densities will occur in the event of a short circuit.
These higher current densities lead to a faster warm up rate in case of a short circuit.
In order to allow the top chip to follow the base chip temperature in time, the gate voltage has to be limited again. These limits have to be much smaller compared to the limits of similar $R_{DS(on)}$ rated classic TEMPFET® devices.

3. Short-circuit protection of Speed-TEMPFET® devices

In this section the short-circuit behaviour of the Speed-TEMPFET® family is described and dimensioning hints are given.

3.1. Influence of temperature on the short-circuit behaviour

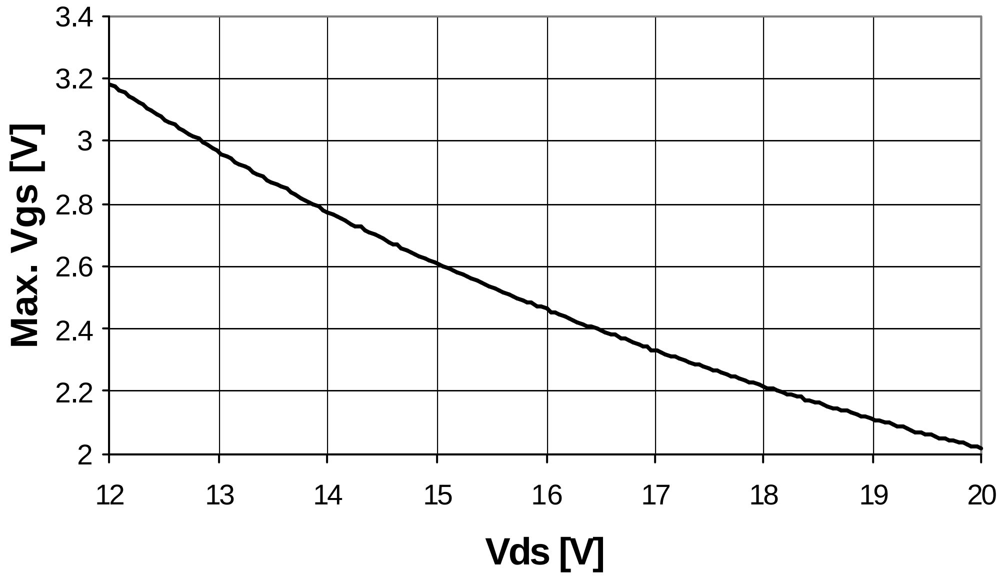
In general there are two major temperature influences on the short-circuit behaviour.
On the one hand side the output characteristic depends on the temperature. On the other hand side the start temperature has effects on how fast the sensor will react. A low starting temperature requires a high thermal energy to be transmitted to the top sensor than a high starting temperature.
Because of both influences the maximum permissible warm up rate must be determined at the lowest possible operating temperature. This generates a maximum permissible gate voltage which is valid for the entire temperature range.

3.2. Parameter for the Speed-TEMPFET® devices

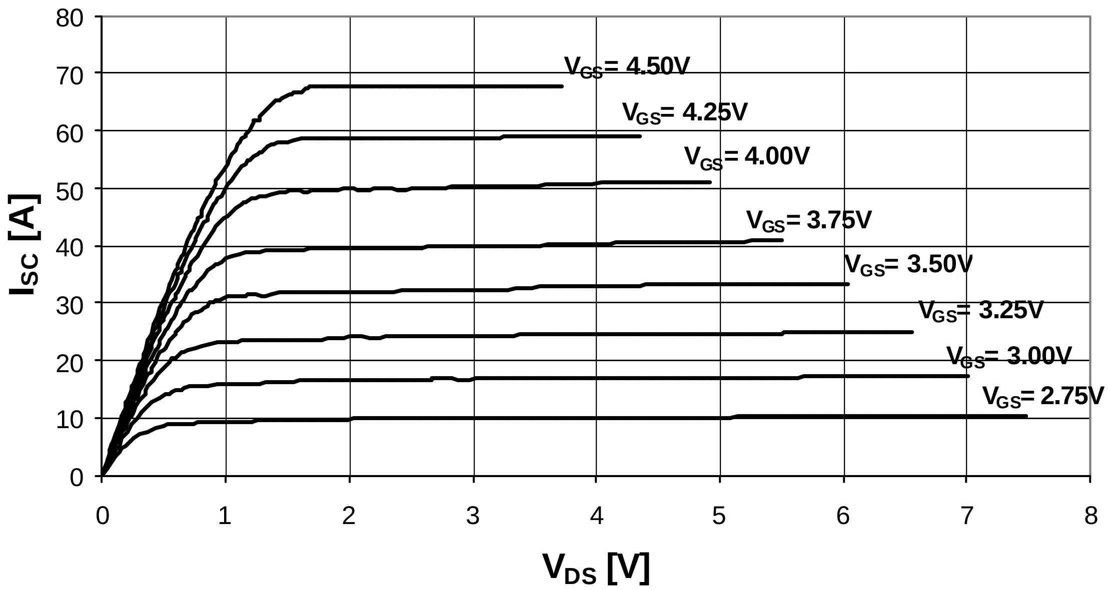
To realise short circuit protection for Speed TEMPFET® devices the Gate voltage has to be limited. In this section diagrams are shown, that ensure full short circuit protection. These diagrams are valid for junction temperatures of T_j= -40 ... 175°C.
If the remaining overall short circuit impedance is that high, that a current limitation due to the FET does not occur at all, the allowed maximum gate source voltage can be much higher provided operation in the safe operating area is ensured.

3.2.1. BTS247Z

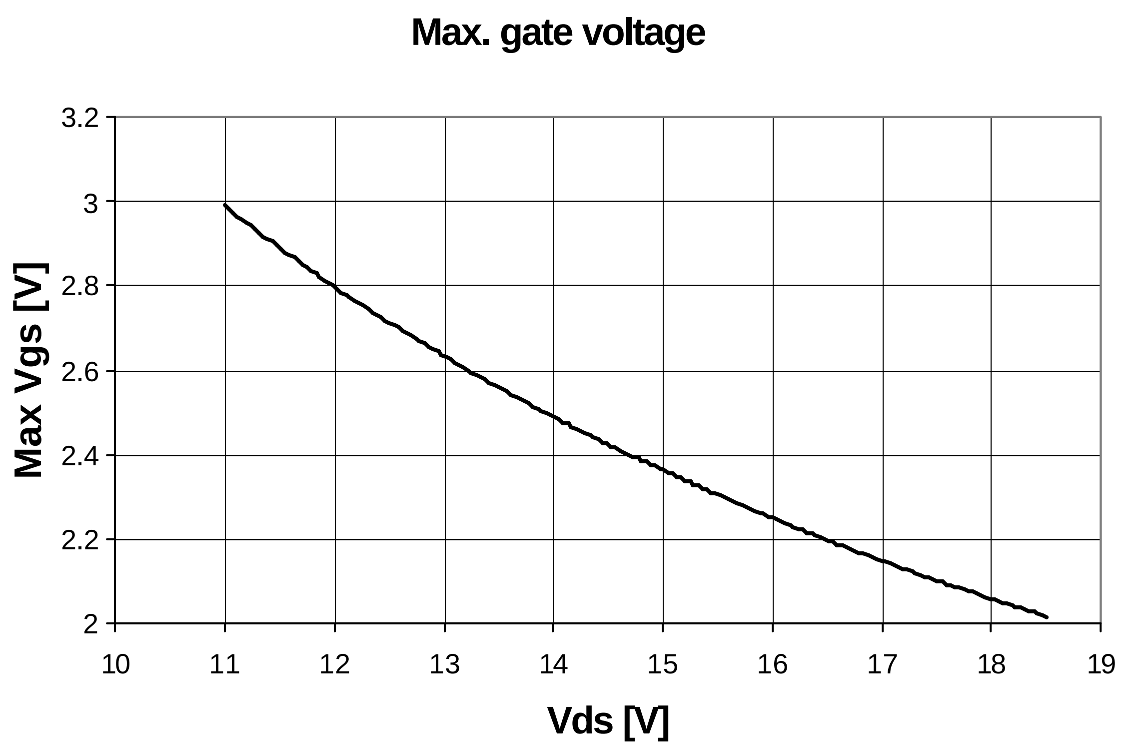
Max. gate voltage

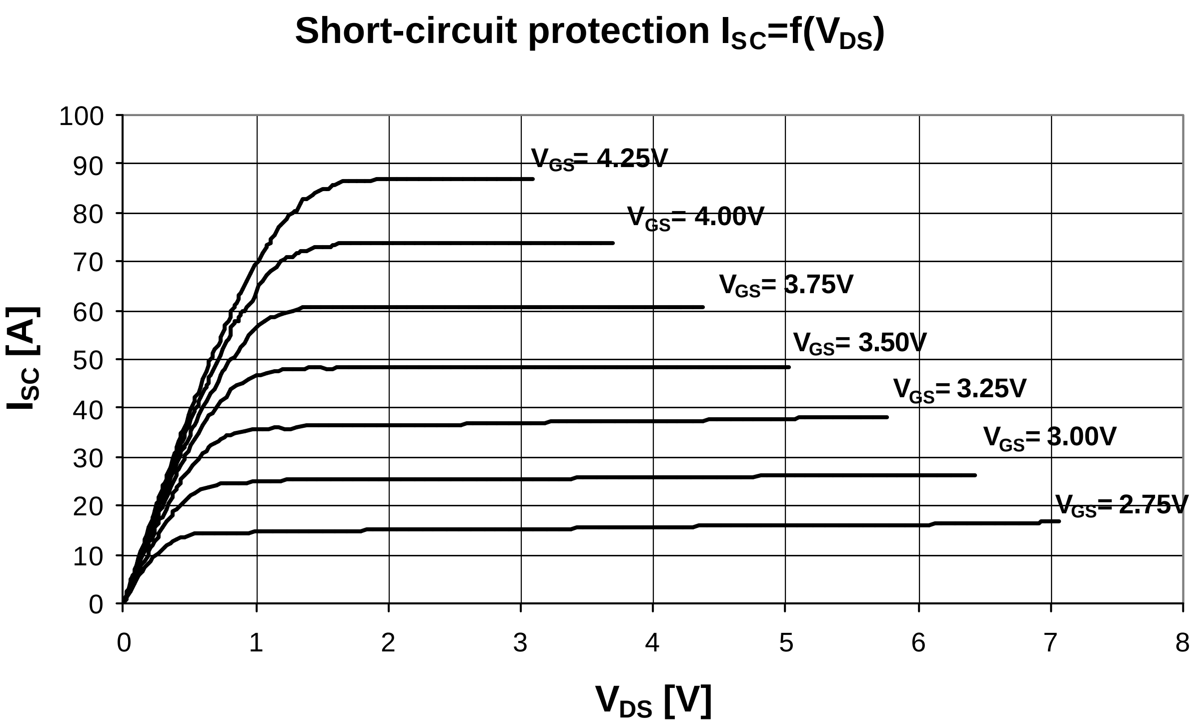


Short-circuit protection I_{SC}=f(V_{DS})

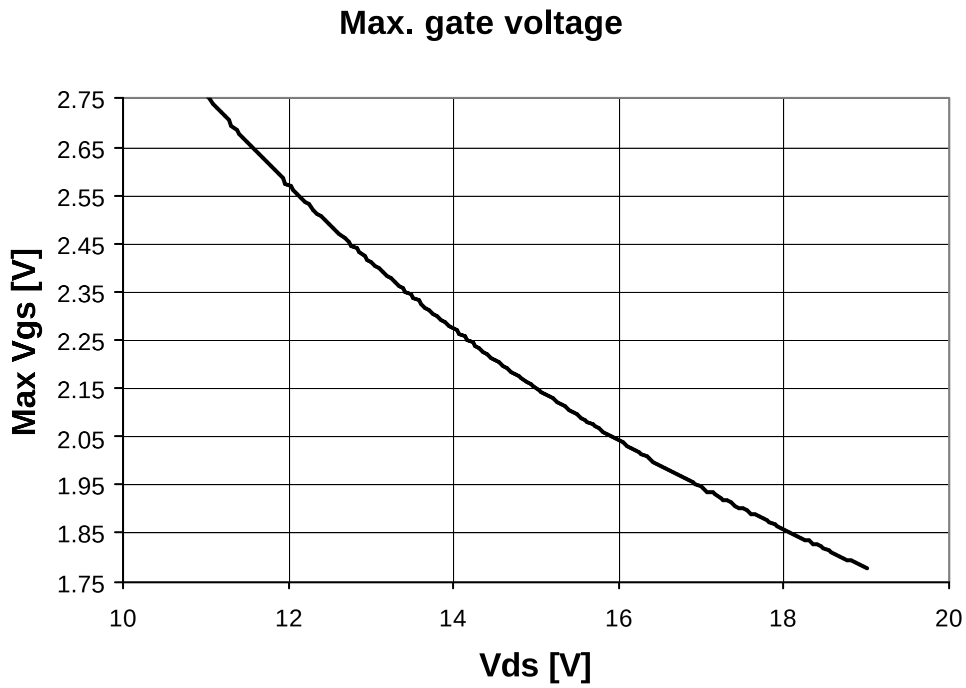


3.2.2. BTS244Z

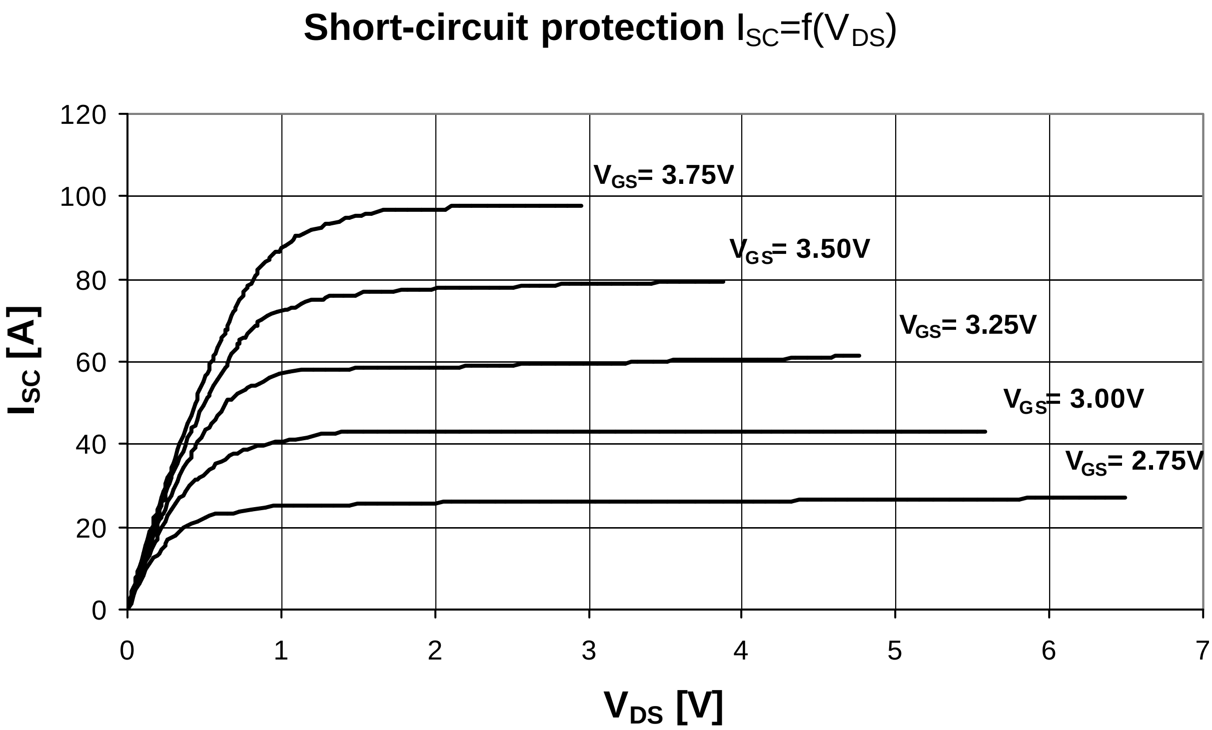

Max. gate voltage
3.2
3
2.8
2.6
2.4
2.2
2
10
11
12
13
14
15
16
17
18
19
Max Vgs [V]
Vds [V]


Short-circuit protection $I_{SC}=f(V_{DS})$
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
V_{GS}= 4.25V
V_{GS}= 4.00V
V_{GS}= 3.75V
V_{GS}= 3.50V
V_{GS}= 3.25V
V_{GS}= 3.00V
V_{GS}= 2.75V
I_{SC} [A]
V_{DS} [V]

3.2.3. BTS282Z



Max. gate voltage
Max Vgs [V]
2.75
2.65
2.55
2.45
2.35
2.25
2.15
2.05
1.95
1.85
1.75
10
12
14
16
18
20
Vds [V]



Short-circuit protection ISC=f(VDS)
ISC [A]
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
VGS= 3.75V
VGS= 3.50V
VGS= 3.25V
VGS= 3.00V
VGS= 2.75V
VDS [V]

3.3. Short-circuit protection exploiting the full RDS(on)

Since limiting of the gate source voltage results in a deterioration of the minimum $R_{DS(on)}$ of the implemented MOSFET, a solution which exploits the full $R_{DS(on)}$ of the MOSFET is often demanded.
A possible solution were the optimum $R_{DS(on)}$ will be sustained and full short circuit protection will be achieved is shown in fig.5.
In this circuit the gate voltage limiting Zener diode D2 is only active as long as the drain source voltage of the Speed-TEMPFET® exceeds a voltage of about 2V. Since high currents cause high drain source voltages the Zener diode D2 will be activated in the event of a short-circuit. By doing so the current will be limited and hence the warm up rate will be limited to acceptable values.

To explain the function of this circuit in more detail, a switch on procedure of a Speed-TEMPFET® is described next.

Initially the input voltage V1 is equal to 0V. Therefore the drain source voltage V_{DS} of the Speed TEMPFET® T1 is equal to V_{bb}.
If V1 rises to 5V, the gate of the Speed TEMPFET® T1 is triggered via R2. The Speed TEMPFET® T1 switches on within a switching time of t_{on}. If R1 and C1 are chosen in that way, that their time constant R1*C1 is much greater than t_{on}, the Zener diode D2 will not be active during switching on.
If now a short-circuit occurs via the load, the drain source voltage V_{DS} of T1 rises and the diode D1 inhibits. As a result C1 will become charged via R1. The transistor T2 switches on as soon as the threshold voltage of T2 is exceeded. After this automatically the Zener diode D2 activates and hence limits V_{GS} of the Speed TEMPFET® T1 and thus the short-circuit current through T1.
The power losses which then occur lead to an activation of the temperature sensor and the user has to switch off again within 1 ms.

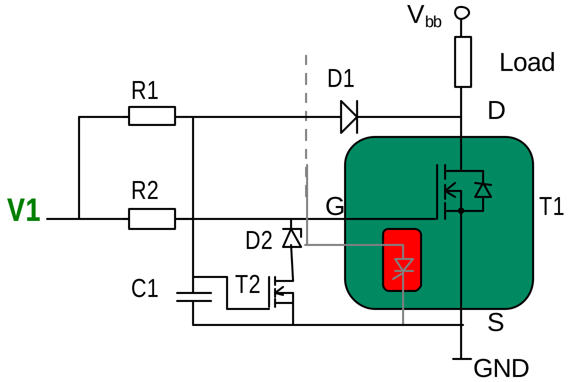


Fig. 5: circuit example with Speed-TEMPFET sustaining full $R_{DS(on)}$

Remark: special attention has to be paid to the voltage range of the Zener diode and especially to the maximum Zener voltage at the given current as it represents the maximum allowed Vgs value in case of a short circuit.

General note:
The information given in this report describes a type of components. It shall not be considered as assured characteristics.