AN50014

Understanding the MOSFET peak drain current rating

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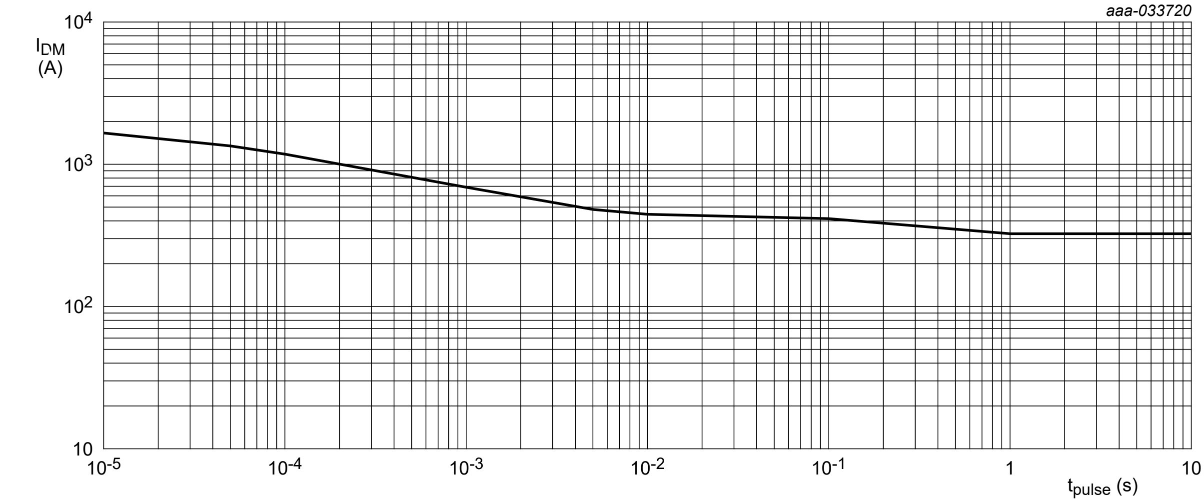
Document information

Information	Content
Keywords	MOSFET, maximum peak drain current
Abstract	This application note provides an explanation of the derivation of the maximum drain current as a function of pulse duration rating.

1. Introduction

I_{DM} is the maximum rated peak drain current for a power MOSFET. It can be defined as a function of the time duration of a rectangular current pulse. I_{DM} is referred to in the Nexperia application note *AN11158* [1] and IEC60747-8 [2].

Recently, in some Nexperia MOSFET data sheets, a graph is included which shows the maximum device peak drain current capability (I_{DM}) expressed as a function of pulse duration. An example from the BUK7S1R0-40H data sheet [3] is shown below in Fig. 1.



V_{GS} = 10 V; T_{mb} = 25 °C; I_{DM} is a single pulse

Fig. 1. Maximum peak drain current capability as a function of pulse duration

In Fig. 1 time is shown logarithmically from 10 µs to 10 s. The maximum allowed peak drain current I_{DM} is also expressed logarithmically.

Historically the I_{DM} capability is shown in the limiting values section of the data sheet for t_p ≤ 10 µs. I_D at DC (continuous) is also shown. I_{DM} is traditionally specified as four times the theoretical value of I_D at DC, see Fig. 2. The I_{DM} rating here is more than four times the I_D as the I_D specified is limited by the package, rather than the silicon itself.

Table 5. Limiting values

In accordance with the Absolute Maximum Rating System (IEC 60134).

Symbol	Parameter	Conditions		Min	Max	Unit
V_{DS}	drain-source voltage	25 °C ≤ T_j ≤ 175 °C		-	40	V
V_{GS}	gate-source voltage	DC; T_j ≤ 175 °C		-10	20	V
P_{tot}	total power dissipation	T_{mb} = 25 °C; Fig. 1		-	375	W
I_D	drain current	V_{GS} = 10 V; T_{mb} = 25 °C; Fig. 2	[1]	-	325	A
I_{DM}	peak drain current	pulsed; t_p ≤10 µs; T_{mb} = 25 °C; Fig. 3		-	1659	A

Fig. 2. BUK7S1R0-40H data sheet limiting values

It is difficult for the user to know what the capability would be at other time durations. Some information can be gleaned from the Safe Operating Area (SOA) graph, however it is still hard to assess the actual capability for different time intervals.

The aim of this new I_{DM} graph is to provide information regarding the current handling capability of the MOSFET for any time duration in the range provided. It should be noted that only the current carrying capability due to conduction losses is considered. Additional losses incurred due to switching events (linear mode and avalanche) may take the device junction temperature beyond the 175 ˚C limit and cause damage to the device.

2. I_{DM} theoretical curve calculation

The power handling capability of the MOSFET can be derived using the transient thermal impedance characteristic (Z_{th}) curve. An example from BUK7S1R0-40H data sheet is shown in Fig. 3 below:

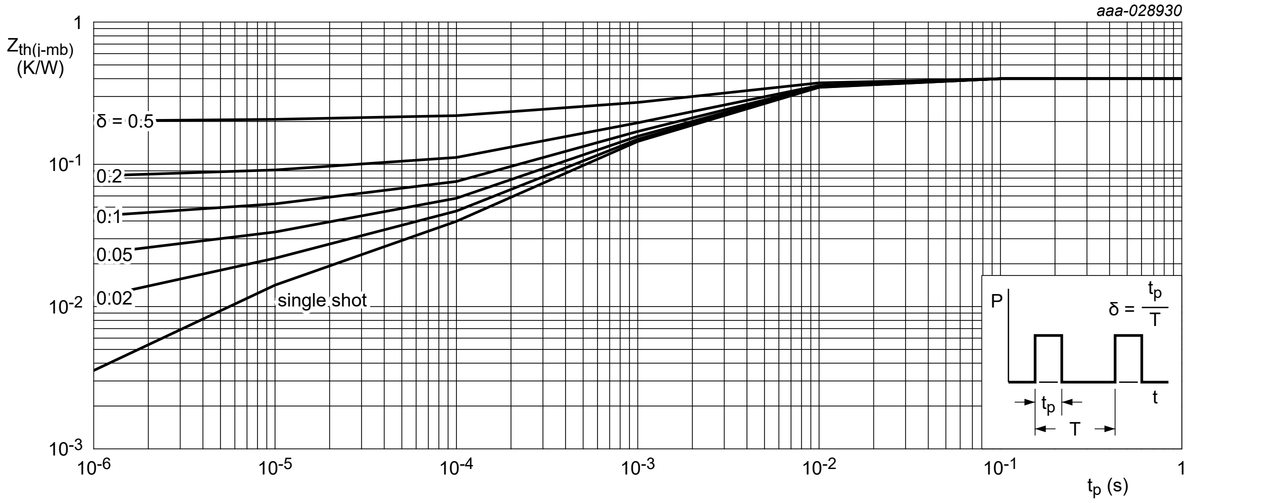


Fig. 3. BUK7S1R0-40H transient thermal impedance as a function of pulse duration

The transient power capability characteristic as a function of time can be determined, assuming that the MOSFET junction temperature would be raised by 150 K, from 25 ˚C to 175 ˚C. See Eq. 1 and Fig. 4.

$$P_{max}(t) = \frac{150}{Z_{th}(t)} \quad (1)$$

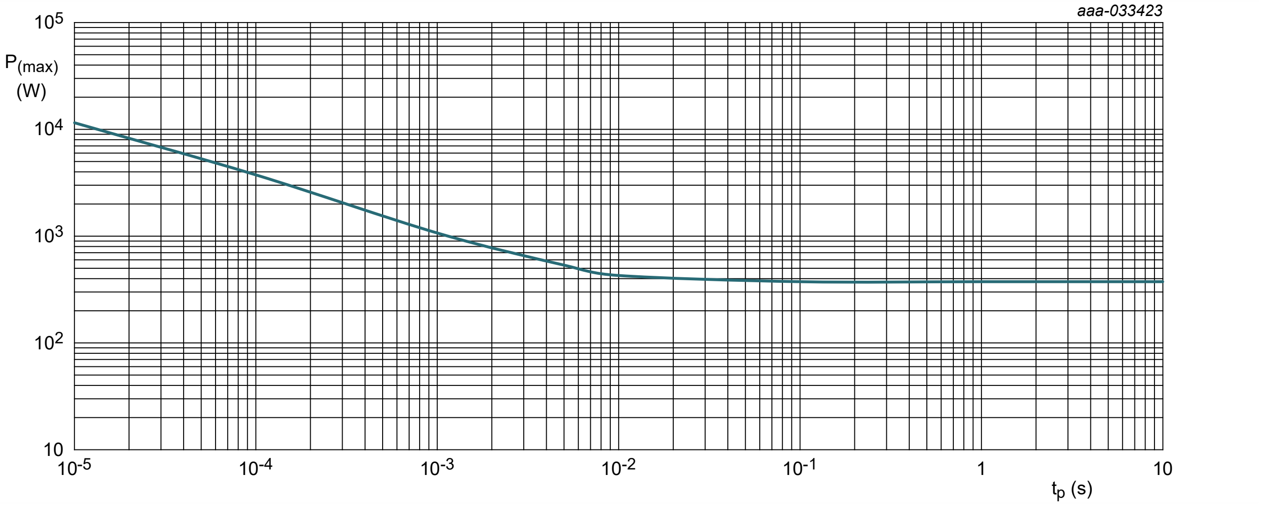


Fig. 4. Peak power capability as a function of pulse duration

To relate power capability to theoretical maximum current, the following relationship is used:

$$I_{DM}(t) = \sqrt{\frac{P_{max}(t)}{R_{DSon}}} \quad (2)$$

R_{DSon} in Eq. 2 is the maximum value specified at 175 ˚C. Using the data sheet value of 2.2 mΩ, a theoretical characteristic based on this formula is shown in Fig. 5.

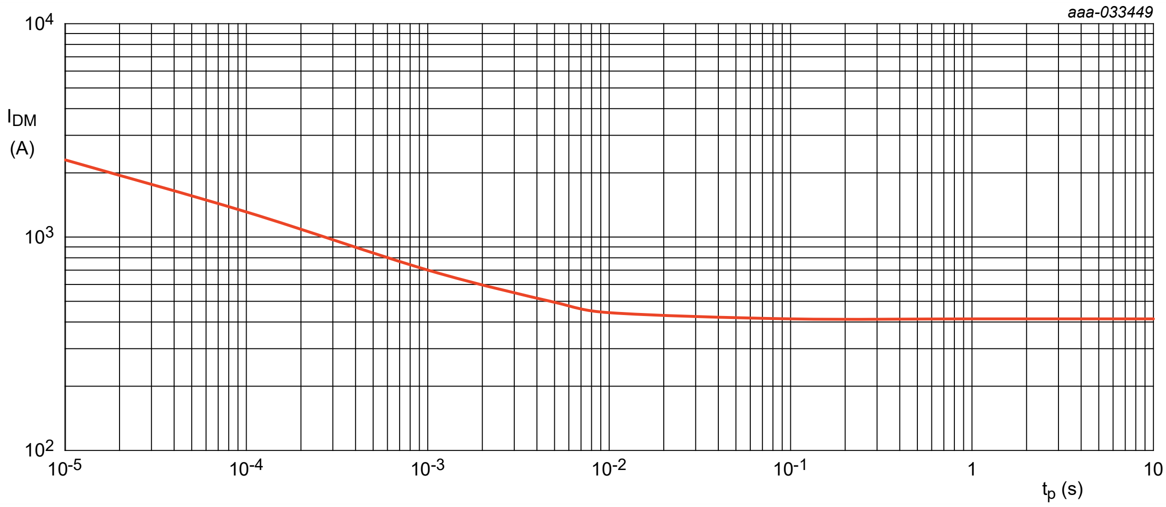
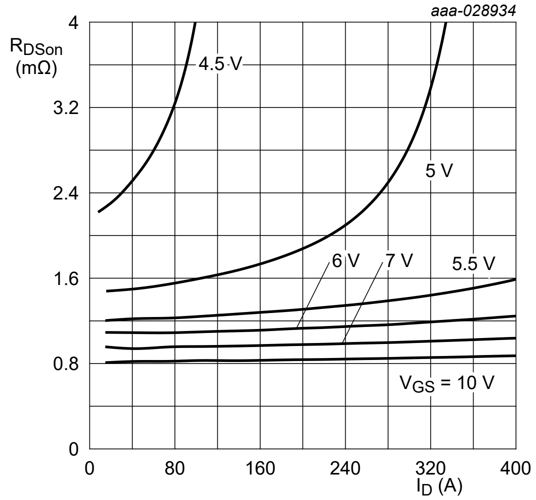


Fig. 5. Peak current capability as a function of pulse duration; calculated values

The maximum theoretical device current for a 10 µs pulse is 2.3 kA, see Fig. 5. However, the R_{DSon} changes with I_D and this is not taken into account with this approach. R_{DSon} value increases with I_D. See the example graph from BUK7S1R0-40H data sheet in Fig. 6 below:



T_j = 25 °C

Fig. 6. BUK7S1R0-40H drain-source on-state resistance as a function of drain current; typical values

The data provided in Fig. 6 is for 25 °C and is only for I_D up to 400 A. Therefore, it cannot be used for I_{DM} estimation. As R_{DSon} dependence on I_D is not taken into account, the data on Fig. 5 is an over estimate. Actual measurement of the device capability is a better way to determine with confidence the current handling capability at various time intervals.

3. Device test method

Devices at Nexperia are measured for I_{DM} from 10 µs pulses up to DC. The devices, depending on their size, are expected to achieve several thousand of Amperes of I_{DM} at 10 µs and few hundred Amperes at DC. For this reason different test gear is used for pulsed and DC measurements.

For pulsed conditions, an in-house designed pulse current tester is used, capable of 5 kA for pulse lengths up to 100 µs. The longest pulse tested is 10 ms. The device is mounted to a specially designed test PCB which ensures low inductance and current. This is important because the pulsed current will have very steep turn-on and turn-off slopes. The thermal capability of the PCB is not critical since at such short pulse intervals no significant heat is transferred to the PCB.

Waveforms showing typical behaviour are shown in Fig. 7 below:

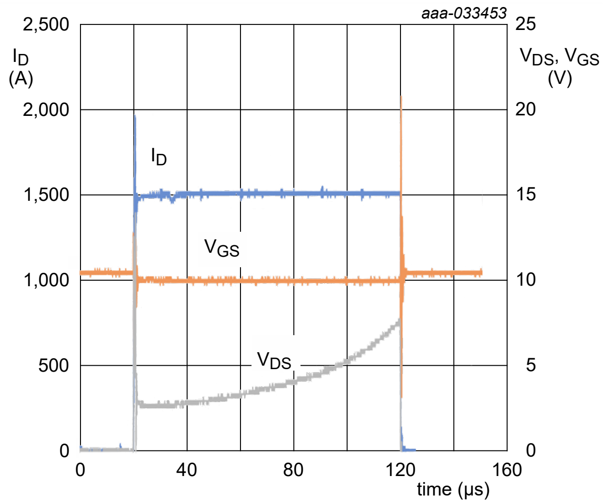


Fig. 7. Drain current, drain-source and gate-source voltages as a function time

In this example a 1,500 A, 100 µs pulse is applied to a device which is already switched on. Initially the voltage drop across the device is around 2.7 V, therefore R_{DSon} is around 1.8 mΩ (2.7 V/1,500 A). At this, initial instance the junction can be considered to be close to 25 °C ambient temperature. According to the device data sheet, at 25 °C the maximum value of R_{DSon} is 1 mΩ at a 25 A test current and the typical value is 0.88 mΩ. As it can be seen in this example, the measured R_{DSon} is roughly double the data sheet value, because of the big difference in the applied current.

As the device heats up, the V_{DS} increases to around 7.5 V. R_{DSon} is therefore around 5 mΩ (7.5 V/1,500 A). This waveform is recorded just before device failure, so it is likely that the junction temperature was higher than 175 ˚C. It may happen that the capability of the device exceeds the tester capability, so the device cannot be tested until destruction, and the true I_{DM} cannot be obtained.

A different tester is used to test DC capability, because the device has to be cooled. The mounting base temperature is kept as close to 25 ˚C as it is practically possible, whilst the junction temperature achieves 175 ˚C. The device must be mounted on a special high thermal conductivity board, in order to ensure that heat is removed from the package as effectively as possible. The device and PCB are then immersed in cooling fluid. Note that these measures to cool the device are required to demonstrate the MOSFET capability and are impractical for most real applications.

Several devices are tested at each time point (from 10 µs to DC). This allows statistical analysis to be performed and suitable derating applied to take into consideration device variability.

4. Measurement results

For this device (BUK7S1R0-40H) the theoretical $I_{D(dc)}$ is 414.75 A. Therefore I_{DM} at 10 μs is determined as per the convention: 4 × 414.75 = 1,659 A.

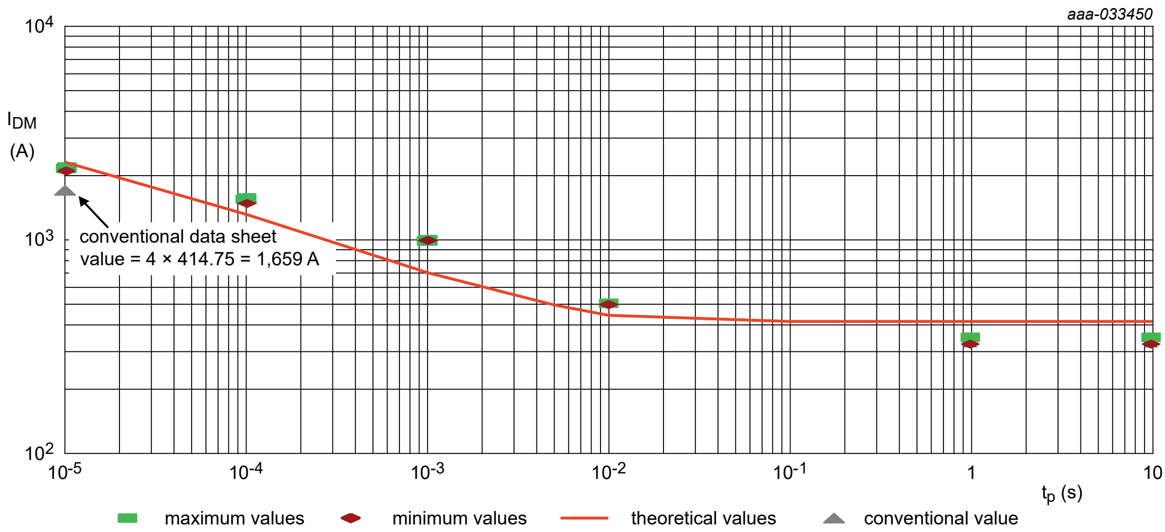


Fig. 8. Peak drain current as a function of pulse duration; measured and calculated values

Considering a small sample of measured devices, I_{DM} at 10 μs achieves around 2.1 kA. As previously suggested, this is less than the value derived on Fig. 5 of 2.3 kA. Fig. 8 demonstrates the relationship between the theoretical and measured values for I_{DM}. The grey triangle denotes the value obtained by convention.

Derating

To guarantee a safe capability curve the measured values are derated by 20%, to consider the fact that T_j will be > 175 ˚C in the measurements and that there will be some batch to batch variation in device performance. The derated peak current at 10 μs is, therefore, reduced to 1,680 A, which is close to the conventionally obtained value. At the DC end of the curve, devices can be measured for 10 s or longer durations, however there is still an untested gap between 10 ms and 10 s. To fill this gap interpolation is used, with the value obtained for 10 s used for the 1 s value.

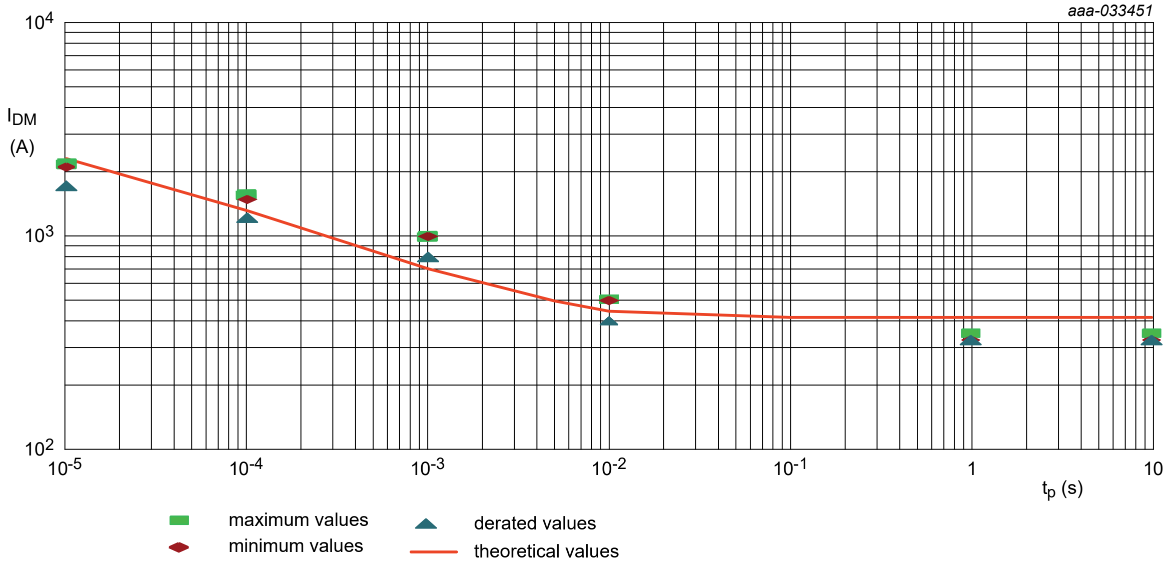


Fig. 9. Peak drain current as a function of pulse duration; derated values

Consequently, the characteristic curve is a theoretical line which is supported by test results. If the derated minimum measured values are above the theoretical line then the theoretical line is the limit, otherwise the derated measurement point will determine the characteristic; see Fig. 10

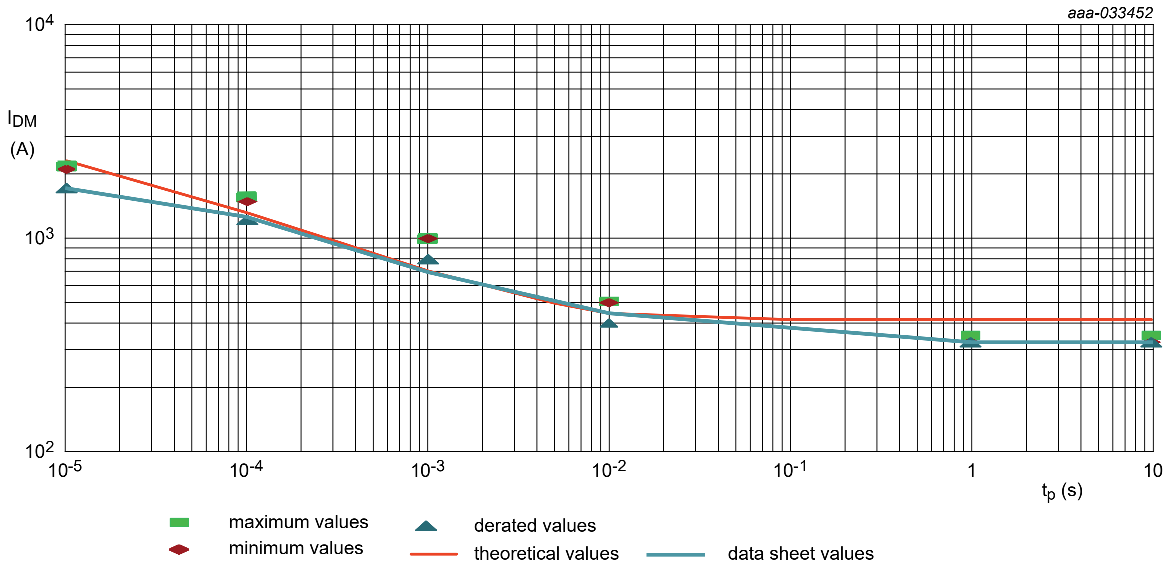
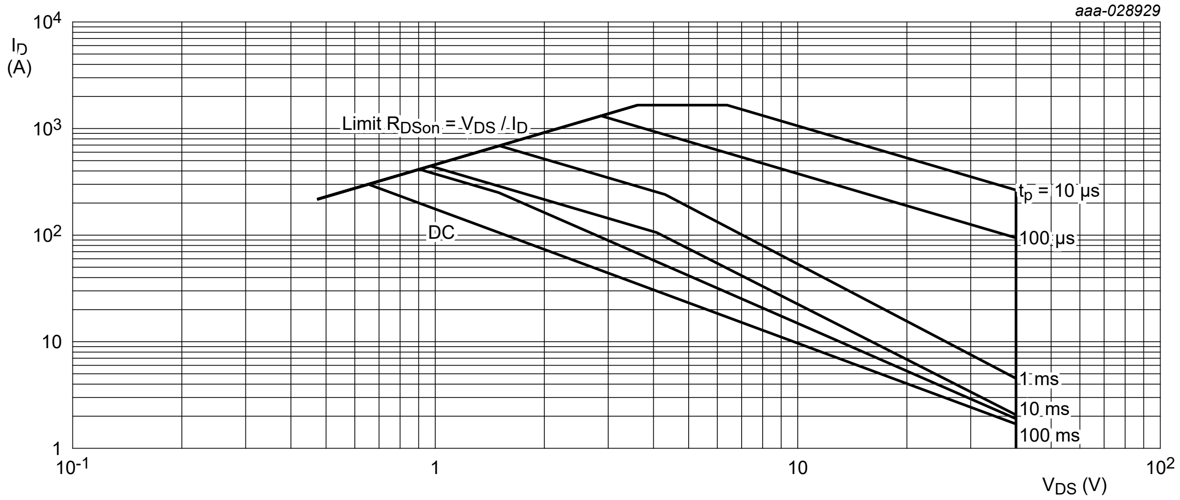


Fig. 10. Peak drain current as a function of pulse duration; data sheet values

Having determined the capability at different pulse durations, this is aligned with other data sheet characteristics such as the Safe Operating Area, example in Fig. 11 below:

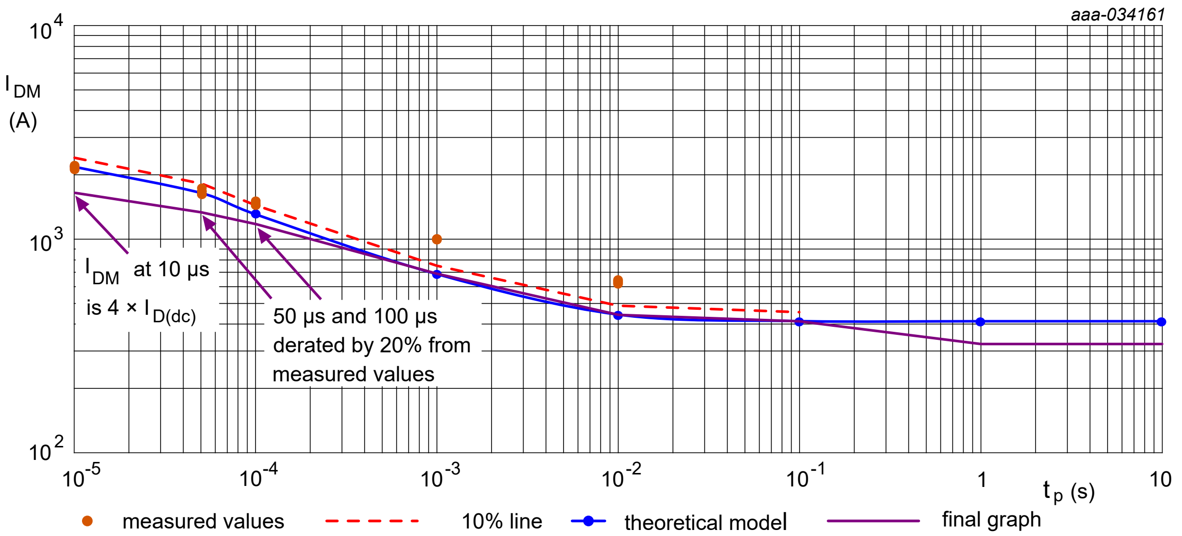


T_{mb} = 25 °C; I_{DM} is a single pulse

Fig. 11. BUK7S1R0-40H Safe operating area; continuous and peak drain currents as a function of drain-source voltage

5. Example of the final IDM curve

The graph shown in Fig. 12 shows the capability of the BUK7S1R0-40H , taking into account the theoretical capability and de-rated measured capability. Fig. 12 also shows a 10% safety line from the measured data points, that is also taken into account when producing the final graph that appears in the data sheets. Due to the combination of the methods for obtaining the data sheet values, Nexperia has a high degree of confidence that this is the practical limit for current handling capability as a function of time.



V_{GS} = 10 V; T_{mb} = 25 °C; I_{DM} is a single pulse

Fig. 12. BUK7S1R0-40H peak drain current capability; measured values, theoretical model, 10% line and final graph

6. References

1. Nexperia application note AN11158
2. IEC IEC 60747-8: 2010
3. Nexperia data sheet BUK7S1R0-40H

7. Revision history

Table 1. Revision history

Revision number	Date	Description
1.0	2022-03-28	Initial version.

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