AN2385
Application note

Power dissipation and its linear derating factor, silicon Limited Drain Current and pulsed drain current in MOSFETs

Introduction

Datasheets of the modern power MOSFET devices, either of low voltage or of high voltage, show in the section entitled "Absolute Maximum Rating" the values of some important parameters that regard the SOA (safe operating area). As it is well kwown in literature, SOA is the area that includes all the I_D-V_{DS} operating points where the device works in safety conditions.

These important parameters are studied in this technical article. In particular, attention will be focused on the Power Dissipation and its Linear Derating Factor, Silicon Limited Drain Current and Pulsed Drain Current. This technical article will explain what these parameters are and how they can be calculated. It will recall some basic and simple technical concepts and can be a useful tool for customers to understand and facilitate reading of a power MOSFET datasheet.

Contents

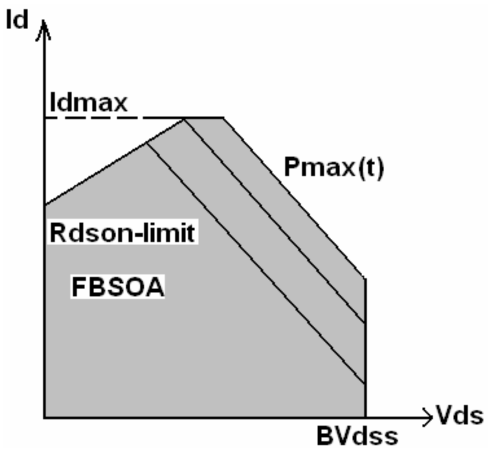
List of figures

List of tables

1 Determination of the SOA limits

SOA is the acronym of Safe Operating Area. It includes all the I_D-V_{DS} operating points inside where the device works in safety conditions. There are two kinds of SOA. The first one is named Forward Biased Safe Operating Area (FBSOA), while the second one is named Reverse Biased Safe Operating Area (RBSOA). FBSOA is the SOA during the device on state, while RBSOA is the SOA when the MOSFET switches off. Supposing that the I_D and V_{DS} axis are in log scale, a typical FBSOA can be depicted as in *Figure 1.*

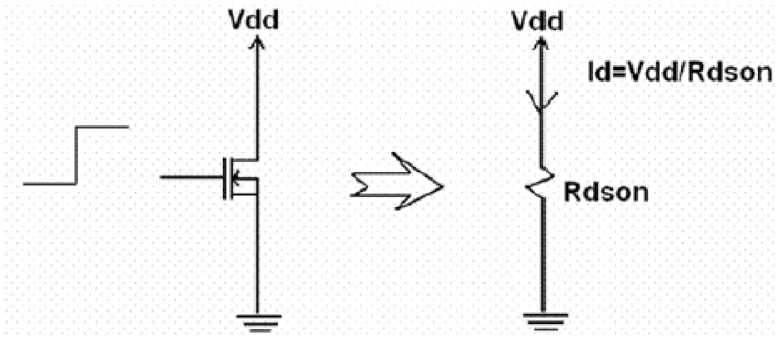
Figure 1. Typical FBSOA of a Power MOSFET



I_{Dmax} is the maximum drain current limit of the MOSFET. It is usually fixed by the wires that connect the drain and source pads to the package pins respectively. BVdss is the maximum drain-source voltage that the device can sustain (breakdown voltage). $P_{max(t)}$ is the maximum power that the device can dissipate. It depends on the junction temperature and power pulse interval time and on the package used. In fact, if the junction temperature overcomes typically 150'C or 175'C, as defined in the automotive devices, the MOSFET could fail or, however, the device works out of the guaranteed temperature spec. Furthermore, increasing the case temperature, the $P_{max(t)}$ value decreases due to a lower energy, which is necessary to bring the junction temperature to the maximum guaranteed value. P_{max} is also a function of the power pulse interval time because, fixing the power pulse, the energy dissipated in the MOSFET, as well as the junction temperature rises, increasing the power interval time. In particular, when the power pulse interval time increases, $P_{max(t)}$ decreases and the SOA area decreases too.

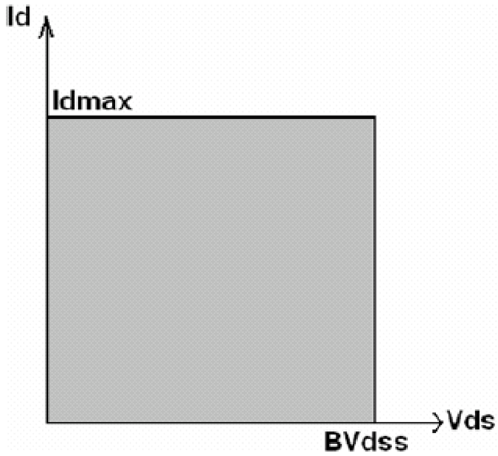
Another limit for FBSOA is established by R_{DSON} of the device. In fact, when the device is in on state without loads connected to the component, all the voltage feed is applied on the drain-source terminals and, thus, the maximum drain current that can flow in the transistor is fixed by V_{DD} and R_{DSON} (*Figure 2.*).

Figure 2. **R_{DSON} limit for MOSFET's FBSOA**



In RBSOA the limits are fixed by the I_{DMAX} and BV_{DSS} (*Figure 3.*).

Figure 3. **Typical RBSOA of a Power MOSFET**



2 Silicon limited drain current

Usually, in every Power MOSFET datasheet the drain current limit is fixed by the package limit. It depends on the kind, number and the size of the wires that connect the drain and the source pads to the respective package pins. However, another important parameter defined in the Power MOSFET datasheets is the Silicon Limited Drain Current. The Silicon Limited Drain Current is the maximum drain current that can flow in the device excluding the package limitation and considering as thermal impedance the junction to case thermal resistance value (R_{THJC}). Furthermore, the Silicon Limited Drain Current is typically calculated considering the device in "on state" with a case temperature equal to 25°C and supposing that it works at the maximum junction temperature. Considering this last operating condition, R_{DSON} must be considered at the maximum junction temperature. It is around two times higher at the ambient temperature (25°C). In thermal equilibrium conditions, the following expression can be written as shown below:

Equation 1

$$T_{JMAX} - 25°C = R_{THJC} \bullet P_{MAX}$$

P_{MAX} is the maximum power that the device can dissipate at the maximum junction temperature. P_{MAX} can be written as:

Equation 2

$$P_{MAX} = R_{DSON(T_{JMAX})} \bullet I^2_{DSL}$$

I_{DSL} is the Silicon Limited Drain Current. I_{DSL} can be written as:

Equation 3

$$I_{DSL} = \sqrt{\frac{T_{JMAX} - 25°C}{R_{DSON(T_{JMAX})} \bullet R_{THJC}}}$$

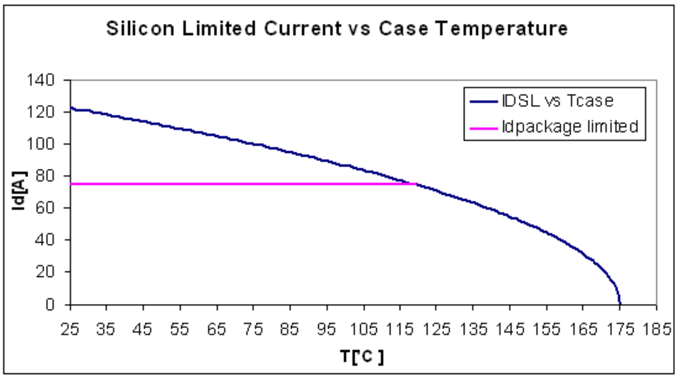
Sometimes, in the Power MOSFET datasheets, the Silicon Limited Drain Current is shown at different case temperature conditions. In this case, the expression of I_{DSL} becomes:

Equation 4

$$I_{DSL}(T) = \sqrt{\frac{T_{JMAX} - T}{R_{DSON(T_{JMAX})} \bullet R_{THJC}}}$$

The Limited Drain Current versus case temperature is also shown in the *Figure 4*. This is considering an example where the junction to case thermal resistance equals 0.5°C/W, the maximum junction temperature is 175°C and the $R_{DSON(TJMAX)}$ equals 16mOhm. In the graph, the Package limited Drain Current is also highlighted (75A).

Figure 4. Silicon limited drain current vs case temperature



For Case Temperatures that are lower of around 110°C, the Package Limited Current is lower than the silicon one and thus, the device Limited Current is fixed at 75A. When the case temperature overcomes 110°C, the device Limited Current equals the Limited Silicon Current.

3 Determination of the power dissipation and its derating factor

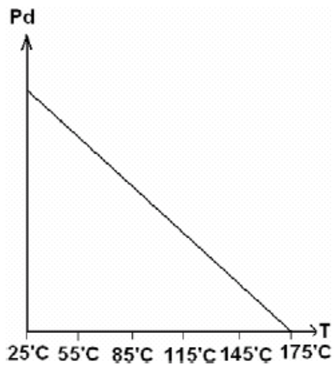
The Power Dissipation value is the maximum power that the device can dissipate in continuous operating mode when the device works in "on state" and the thermal impedance is only due to R_{THJC}. The power dissipation depends on the case temperature. Typically, in Power MOSFET datasheets, it is reported at ambient temperature (25°C). In order to calculate the power dissipation value the consider R_{DSON} value must be considered at the maximum junction temperature. It is possible to demonstrate that such value is around two times the values of R_{DSON} at ambient temperature considering the data measured. Power Dissipation can be written as:

Equation 5

$$P_{D_{(T=25^\circ C)}} = R_{DSON(T_{JMAX(I_{DSL})})} \bullet I_{DSL}^2 = \frac{T_{JMAX-25^\circ C}}{R_{THJC}}$$

Furthermore, P_D can be established for any other fixed operation case temperature considering that the guaranteed maximum junction temperature is 150°C or 175°C (see *Figure 5.*).

Figure 5. Power dissipation vs T



The Linear Derating Factor of Power Dissipation factor is defined as the angular coefficient of the line shown in *Figure 5.* It can be calculated as:

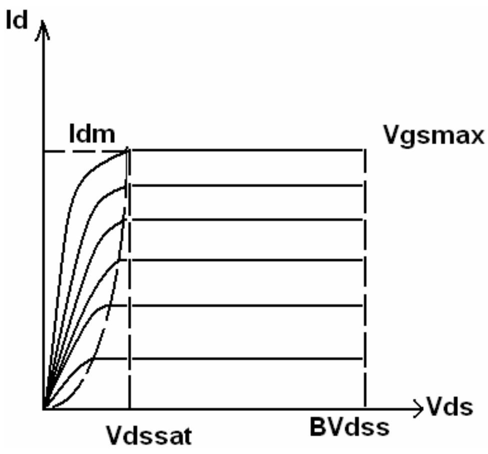
Equation 6

$$\frac{\partial P_D}{\partial T} = \frac{P_{D_{(T=25^\circ C)}}}{T_{JMAX-25^\circ C}} = \frac{1}{R_{THLJC}}$$

4 Pulsed drain current (I_{DM})

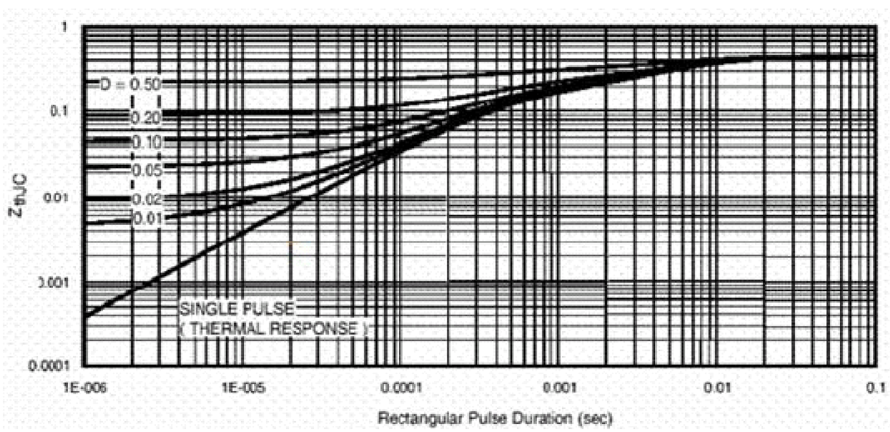
The Pulsed Drain Current (I_{DM}) is the maximum current that the device can bring, excluding the package limitation and considering a very short power pulsed interval time. It depends on the guaranteed maximum gate-source voltage and on the device trans-conductance at the specific I_{DM}. In particular, I_{DM} is the current that the device can bring with an applied gate voltage equal to the guaranteed maximum permissible gate-source value when the transistor works in switching mode and not in the linear zone (see *Figure 6.*).

Figure 6. I_{DM} determination considering the output characteristic



In order to establish the Pulsed Drain Current interval time, avoiding that the junction temperature overcomes the maximum guaranteed value, the Junction to Case Maximum Effective Transient Thermal Impedance must be considered (see *Figure 7.*).

Figure 7. Junction to case maximum effective transient thermal impedance for TO-220 package.



Considering that the Dissipated Power is equal to:

Equation 7

$$P_D = R_{DSON(175°(C,\ I_{DM}))} \bullet I_{DM}^2$$

where $R_{DSON(175°C@IDM)}$ is the on resistance of the device at the guaranteed maximum junction temperature and at the Pulsed Drain Current value, and that:

Equation 8

$$P_D \bullet Z_{THJC} = \Delta T = T_{JMAX} - 25°C$$

where Z_{THJC} is the junction to case thermal impedance at the specific operation conditions, the maximum acceptable Z_{THJC} value can be achieved as:

Equation 9

$$Z_{THJC} = \frac{T_{JMAX} - 25°C}{R_{DSON175°(C,\ I^2_{DM})}}$$

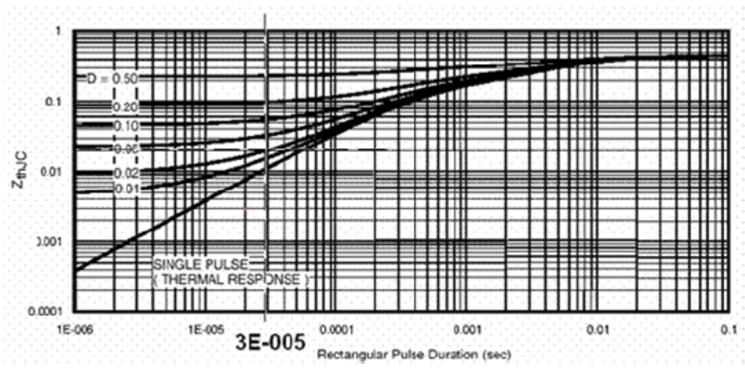
Thus, considering a specific Power Pulse with a fixed duty cycle, the maximum Rectangular Pulse Duration can be achieved.

As example, *Figure 8.* shows the determination of the maximum Rectangular Pulse Duration considering a Pulsed Drain Current equal to 600A, T_{JMAX} of 175°C, case temperature of 25°C, duty cycle of 0.02 and $R_{DSON(175°C,\ IDM)}$ equal to 20mOhm. Z_{THJC} can be calculated as:

Equation 10

$$Z_{THJC} = \frac{175°C - 25°C}{20 \bullet 10^{-3} \bullet 600^2} = 0.021 \bullet \frac{°C}{W}$$

Figure 8. Determination of the maximum rectangular pulse duration



In this example, the maximum Rectangular Pulse Duration equals 30usec. For power pulse of higher duration the junction temperature overcomes 175°C and the device could fail.

It is important to highlight that the measured on resistance must be performed at the maximum junction temperature and also at the specific Pulsed Drain Current. In fact, increasing the drain current also R_{DSON} increases and thus, of course, this effect must be taken into account.

5 Conclusions

This technical article has explained what the Power Dissipation and its Linear Derating Factor, Silicon Limited Drain Current and Pulsed Drain Current (I_{DM}) in MOSFET datasheets are and how they can be calculated. Furthermore, attention has also been placed on the definition of the MOSFETs SOA (FBSOA and RBSOA) and on the Junction to Case Maximum Effective Transient Thermal Impedance.

6 Revision history

Table 1. Revision history

Date	Revision	Changes
13-Jun-2006	1	Initial release