How to Use MOSFET RDSon Data from the Datasheet

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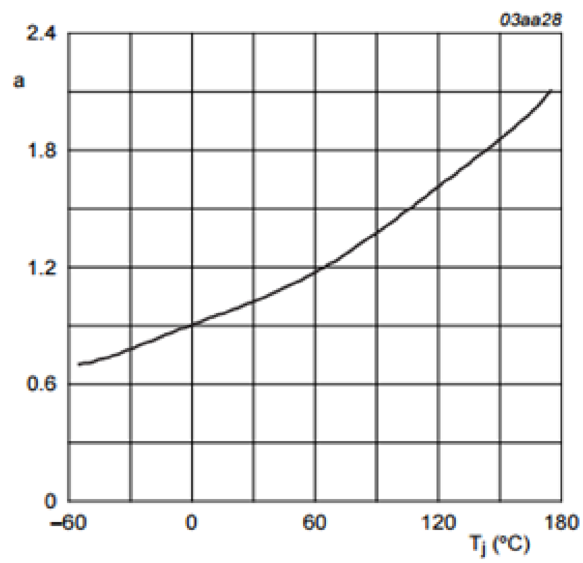
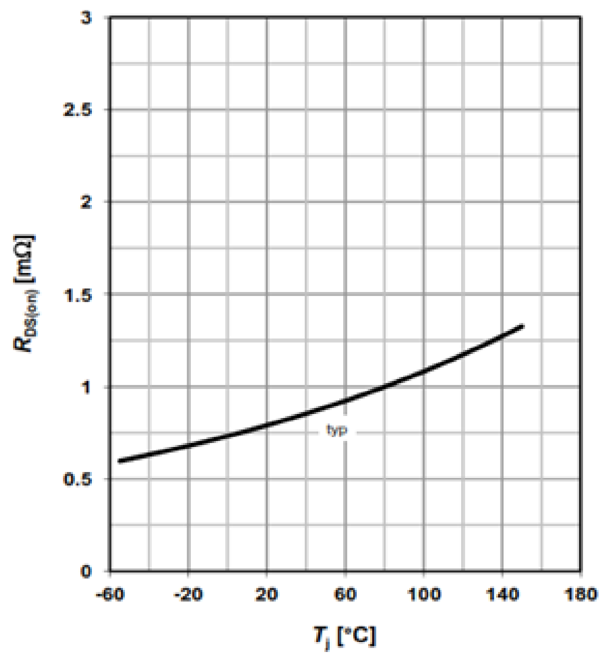
In this article I will discuss the proper way on how to use MOSFET RDSon data provided by datasheets. RDSon is a channel on state resistance of MOSFET. This is provided in the data sheet taken from different conditions like below table.

R_{DSon}	drain-source on-state resistance	V_{GS} = 10 V; I_D = 500 mA; T_j = 25 °C; see Figure 6; see Figure 8	-	2.8	5	Ω
		V_{GS} = 10 V; I_D = 500 mA; T_j = 150 °C; see Figure 6; see Figure 8	-	-	9.25	Ω
		V_{GS} = 4.5 V; I_D = 75 mA; T_j = 25 °C; see Figure 6; see Figure 8	-	3.8	5.3	Ω

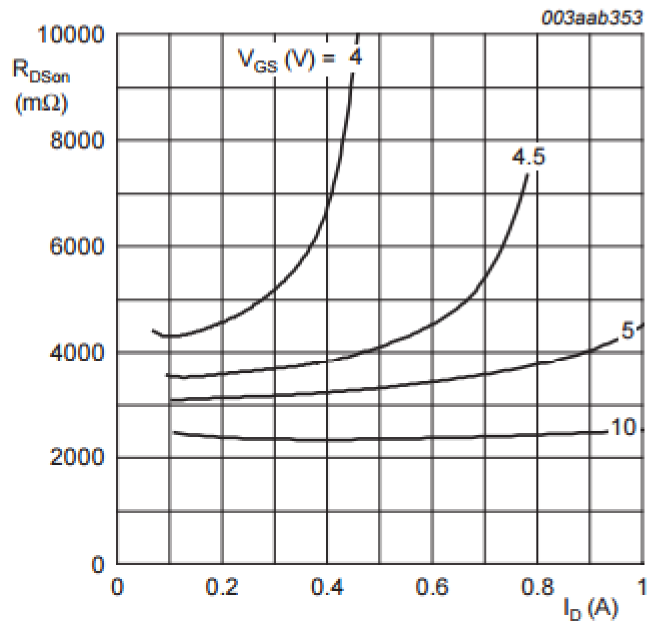
There is also a graph between RDSon or normalized RDSon value and temperature like below.



$$a = \frac{R_{DSon}}{R_{DSon(25°C)}}$$



Some datasheet also provides RDSon versus drain current that is taken at nominal ambient temperature like below



$$T_j = 25\,°C$$

What RDSon I should select? Well, you can go for the worst case for quick design analysis. However, if you want to know how to use MOSFET RDSon data that is more realistic, continue on reading below.

How to Use MOSFET RDSon Data that Gives Realistic Result

As mentioned above, you may consider directly the worst case scenario for easier analysis. However, the result is not that realistic with respect to your needs. For instance, the worst case RDSon using below table are **2.8 ohms** and **9.25 ohms**.

R_{DSon}	drain-source on-state resistance	V_{GS} = 10 V; I_D = 500 mA; T_j = 25 °C; see Figure 6; see Figure 8	-	2.8	5	Ω
		V_{GS} = 10 V; I_D = 500 mA; T_j = 150 °C; see Figure 6; see Figure 8	-	-	9.25	Ω
		V_{GS} = 4.5 V; I_D = 75 mA; T_j = 25 °C; see Figure 6; see Figure 8	-	3.8	5.3	Ω

To compute for the drain current, the worst case is the smallest value since it will give the highest drain current. In solving for the power dissipation, the worst case is the highest value.

The more realistic approach is to consider a single RDSon corresponding to a particular condition. For instance, the design maximum operating temperature is 60'C ambient; then get the corresponding RDSon for this.

Example #1 on How to Use MOSFET RDSon Data

<u>Design requirements:</u>

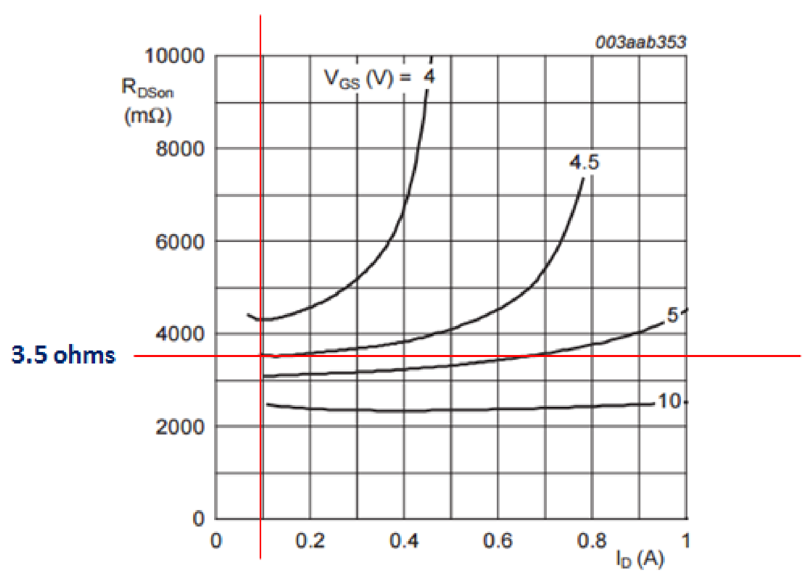
Ambient temperature range: maximum 60'C

Drain current: 100mA

Applied VGS: 4.5V

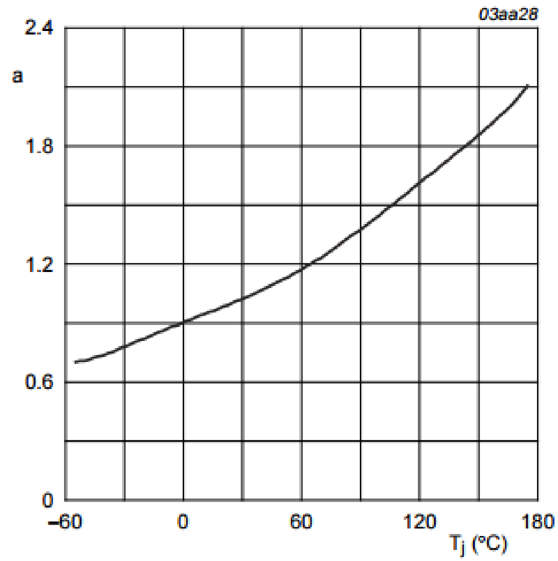
MOSFET P/N: 2N7002

For 2N7002, I see the graph below. It seems perfect for the requirement.



$T_j = 25°C$

From the graph, I get **3.5 ohms**. However, this is only taken at a junction temperature (Tj) of 25'C. Our target is to get the RDSon at 60'C ambient. From the datasheet, I also see this graph.



$$a = \frac{R_{DSon}}{R_{DSon(25°C)}}$$

Fig 8. Normalized drain-source on-state resistance factor as a function of junction temperature

This is a normalized RDSon with respect to junction temperature. The value we derived above which is **3.5 ohms** will be multiplied by a factor that is found on this graph.

My objective is to get the RDSon at 60'C ambient; can I use the information at the junction temperature of 60'C on the above graph? It's better not. There is a relation between junction and ambient temperatures as given by below equation.

$$\mathrm{Tj} - \mathrm{Ta} = \mathrm{P_D} \times \mathrm{Rth(j - a)}$$

What we can get from the above equation is the temperature difference between the junction and ambient (Tj-Ta). We know the drain current which is given at 100mA. Based from this drain current we will compute for the power dissipation P_D using below equation

$$P_D = {I_D}^2 \times RDSon$$

In order to get the power dissipation, we need the RDSon. In this equation, we are going to use the typical RDSon value we get earlier that is **3.5 ohms**. So, the power dissipation is

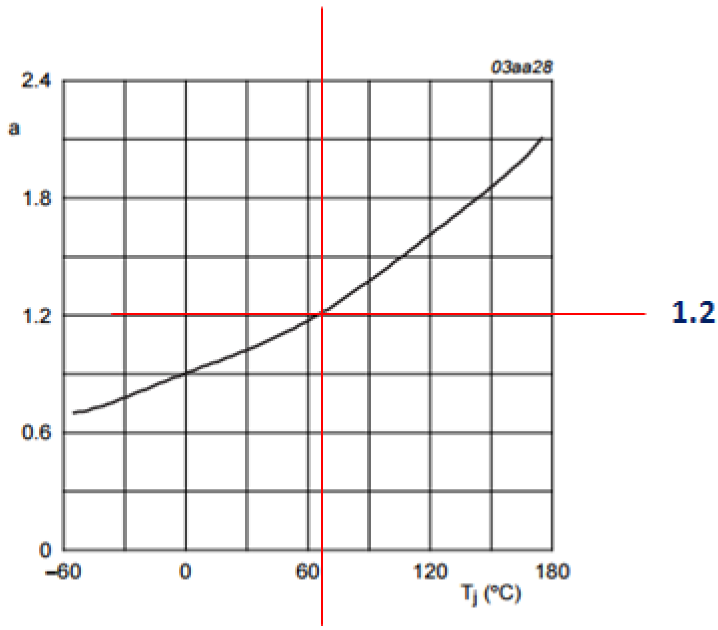
$$P_D = {I_D}^2 \times RDSon = (0.1A)^2 \times 3.5\Omega = 35mW$$

And the temperature difference is

$$Tj - Ta = P_D \times Rth(j - a) = 35mW \times \frac{350K}{W} = 12.25'C$$

(Note: for 2N7002, the Rth(j-a) is 350K/W)

Finally, we get the delta temperature between junction and ambient. So, for an ambient of 60’C, the equivalent junction temperature is 60’C+12.25’C = 72.25’C. The multiplier we need is 1.2 based from the graph below.



$$a = \frac{R_{DSon}}{R_{DSon(25°C)}}$$

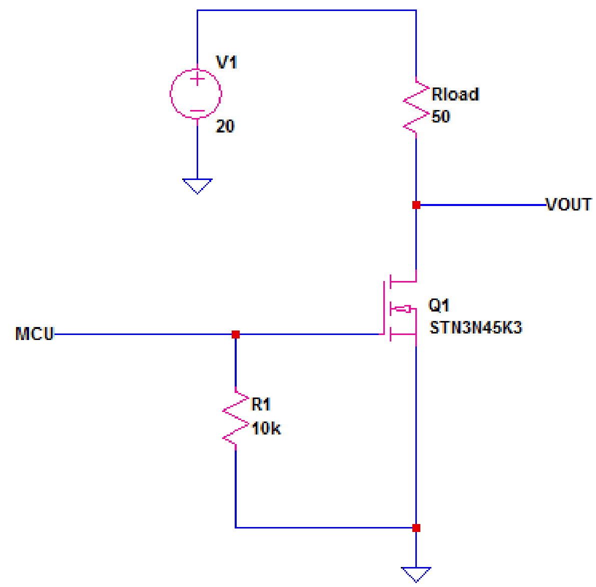
Fig 8. Normalized drain-source on-state resistance factor as a function of junction temperature

Therefore, the RDSon to be used at an ambient temperature of 60’C is

$$\mathrm{RDSon}_{60\mathrm{C}} = 3.5\Omega \times 1.2 = \mathbf{4.2}\Omega$$

Example #2 on How to Use MOSFET RDSon Data

Ambient temperature range: maximum 100’C



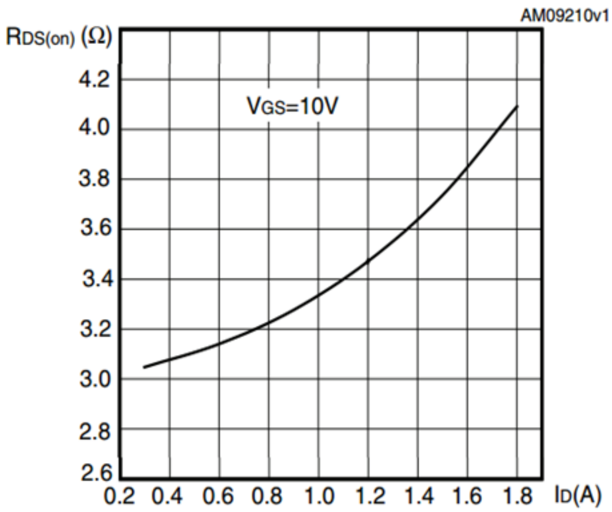
In this second example, I will show you the way on how to use MOSFET RDSon data for STN3N45K3 N-channel MOSFET from ST Microelectronics.

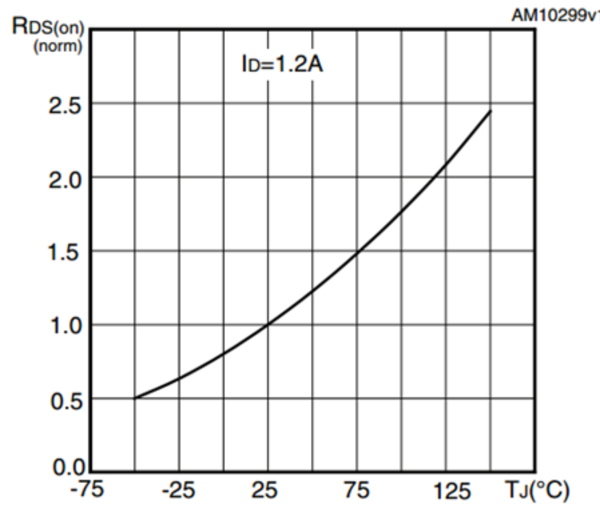
Based on the STN3N45K3 datasheet

(T_C = 25 °C unless otherwise specified)

Table 4. On /off states

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{(BR)DSS}$	Drain-source breakdown voltage	I_D = 1 mA, V_{GS} = 0	450			V
I_{DSS}	Zero gate voltage drain current (V_{GS} = 0)	V_{DS} = 450 V V_{DS} = 450 V, T_C=125 °C			1 50	µA µA
I_{GSS}	Gate-body leakage current (V_{DS} = 0)	V_{GS} = ± 20 V			± 10	µA
$V_{GS(th)}$	Gate threshold voltage	V_{DS} = V_{GS}, I_D = 50 µA	3	3.75	4.5	V
$R_{DS(on}$	Static drain-source on resistance	V_{GS} = 10 V, I_D = 0.6 A		3.3	4	Ω





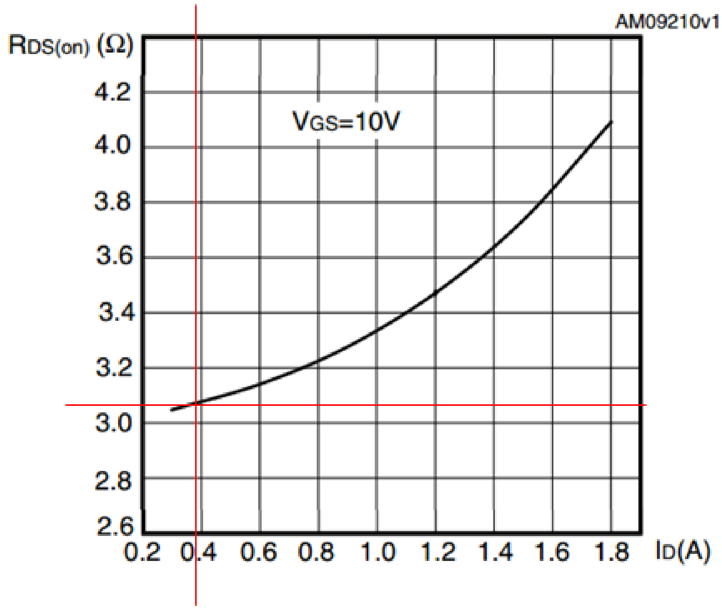
Our circuit uses MCU pin voltage to the gate. MCU pin is can be 3.3V or 5V. The table above specified RDSon value that is taken at VGS = 10V and I_D = 0.6A. The graph also shows only a curve with VGS = 10V. If you want to, you can ask another curve from the manufacturer specific for your needs for more exact analysis. In my case, I just make use of these informations.

First, we will estimate the drain current of our circuit. The drain current is opposed by Rload and the RDSon of the MOSFET. For this estimation, we can use the typical RDSon from the table above which is **3.3 ohms**. So, the drain current is

$$I_D = \frac{20V}{50\Omega + 3.3\Omega} = \mathbf{375.23mA}$$

If you want, you may not consider the RDSon in the estimation of the drain current. If so, the computed drain current is just equal to 0.4A.

From the drain current versus RDSon graph, the RDSon is around **3.08 ohms** when the drain current is around **375mA** as shown below.



This value is just for junction temperature of 25’C as datasheet said. Our goal is to get the RDSon at 100’C ambient temperature.

Again, we need to solve for the temperature difference between junction and ambient as we did on the first example.

$$\mathrm{Tj} - \mathrm{Ta} = \mathrm{P_D} \times \mathrm{Rth(j-a)}$$

$$\mathrm{Tj} - \mathrm{Ta} = \mathrm{I_D}^2 \times \mathrm{RDSon} \times \mathrm{Rth(j-a)}$$

$$\mathrm{Tj} - \mathrm{Ta} = (375.23\mathrm{mA})^2 \times 3.08\Omega \times \frac{37.8'\mathrm{C}}{\mathrm{W}} = \mathbf{16.4'C}$$

Where $\mathrm{Rth(j-a)}$ is given below

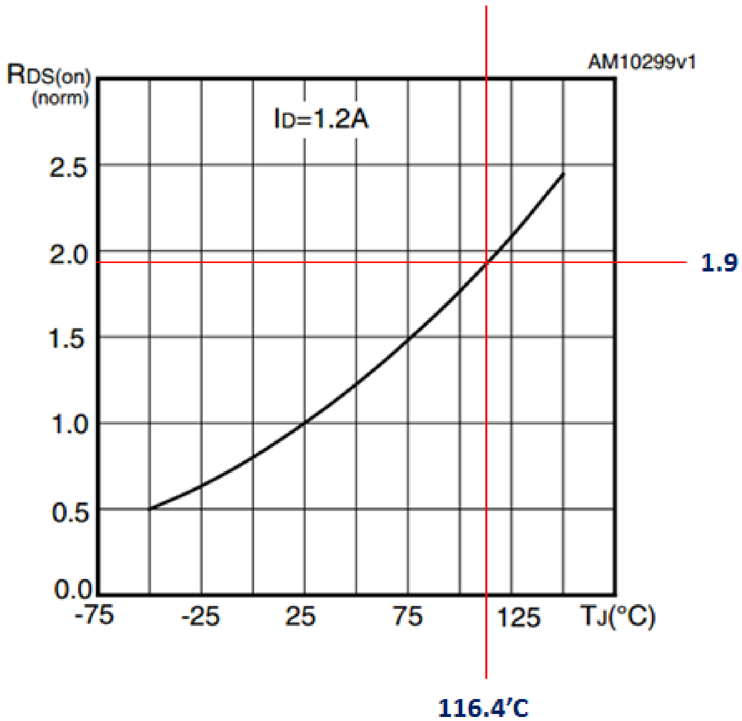
Table 3. Thermal data

Symbol	Parameter	Value	Unit
R_{thj-a} (1)	Thermal resistance junction-ambient	37.8	°C/W

1. When mounted on FR-4 board of 1 inch^2 , 2oz Cu, t < 30 sec

So, for 100'C ambient, the equivalent junction temperature will be 100'C+16.4'C = **116.4'C.**

Based from the normalized RDSon curve, the multiplier is **1.9**.

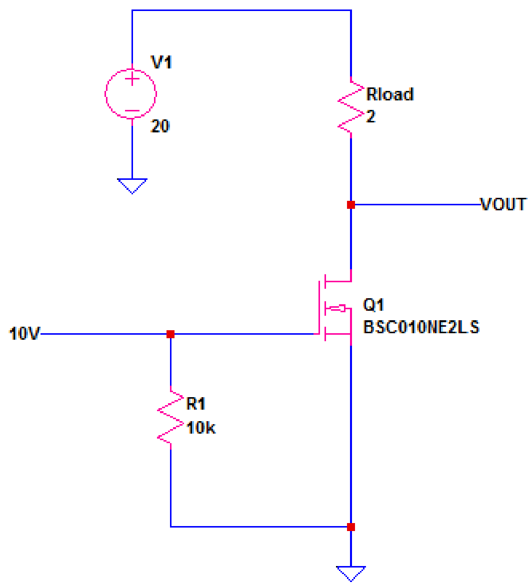


Therefore, the RDSon at 100'C ambient temperature is

$$RDSon_{100C} = 3.08\Omega \times 1.9 = \mathbf{5.852}\Omega$$

Example #3 on How to Use MOSFET RDSon Data

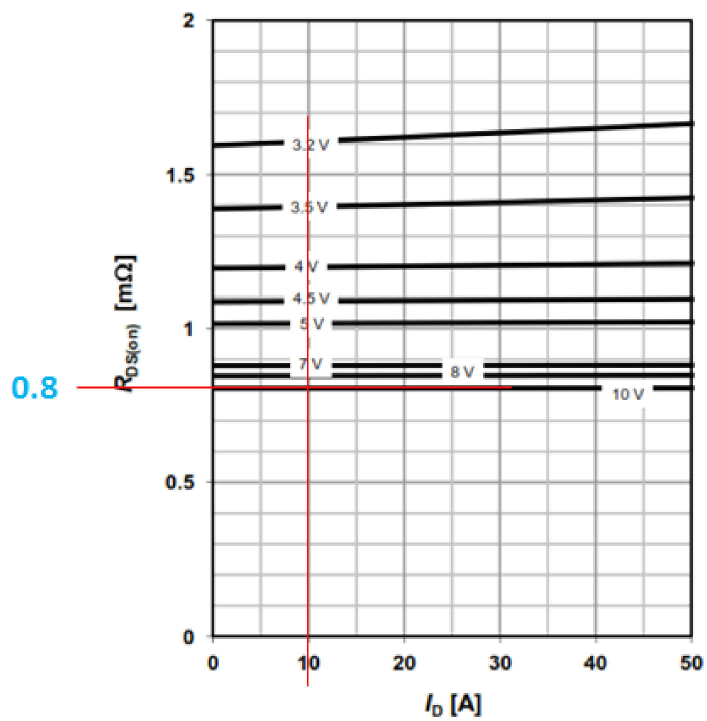
In this last example on how to use MOSFET RDSon data, I will use a power MOSFET in a circuit below. The requirement is to get the MOSFET RDSon at 100'C case temperature.



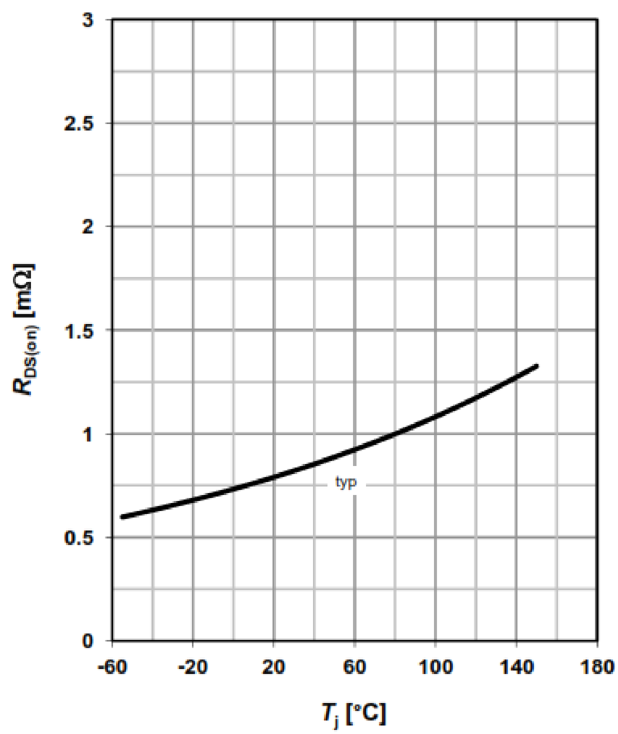
First we need to get the drain current using the typical RDSon. The typical RDSon of this device based on datasheet is very small which is 0.001 ohm; it can be neglected in solving for the drain current.

$$I_D = \frac{20V}{2\Omega} = 10A$$

From the drain current versus RDSon with VGS of 10V, the typical RDSon is 0.8milliohm as shown below.



The RDSon we get above is typical. So, we need to use the normalized RDSon table below to get the target RDSon.



However, the specified temperature for the target RDSon is 100'C case temperature but the graph above uses junction temperature. Like we did in the previous examples, we will derive the junction temperature corresponds to the specified case temperature. We can use below relation

$$\mathrm{Tj} - \mathrm{Tc} = \mathrm{P_D} \times \mathrm{Rth(j-c)}$$

(Note: Tj-Tc is the temperature difference between junction and case, Rth(j-c) is the thermal resistance junction to case)

The MOSFET circuit above is a normal on/off switch so we just consider only the RDSon loss in the power dissipation. If the above circuit is use in switching converter that continuously switching on and off many times in a high frequency rate, we need to consider the switching losses. So

$$\mathrm{Tj} - \mathrm{Tc} = \mathrm{P_D} \times \mathrm{Rth(j-c)}$$

$$\mathrm{Tj} - \mathrm{Tc} = \mathrm{I_D}^2 \times \mathrm{RDSon} \times \mathrm{Rth(j-c)}$$

$$Tj - Tc = (10A)^2 \times 0.0008\Omega \times \frac{20K}{W} = 1.6'C$$

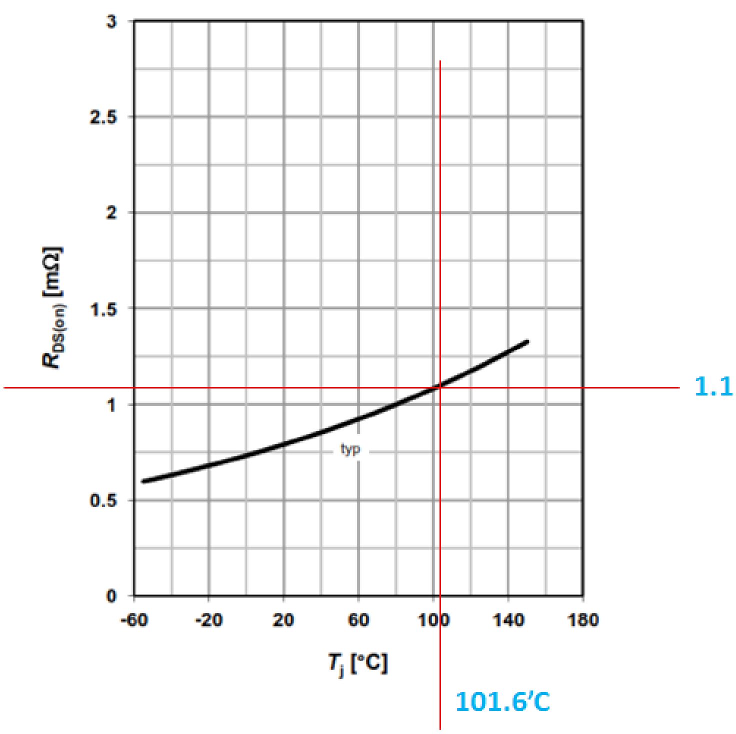
Where Rth(j-c) is

Thermal characteristics

Thermal resistance, junction - case	R_{thJC}		-	-	1.3	K/W
		top	-	-	20	
Device on PCB	R_{thJA}	6 cm^2 cooling area[2)]	-	-	50	

The difference between the junction and case temperatures is only 1.6'C. So, for 100'C case, the equivalent junction temperature is 100'C+1.6'C = **101.6'C**.

Now, we can use the normalized RDSon graph to get the required RDSon.



Therefore, the RDSon to use for 100'C case temperature is

$$\mathrm{RDSon}_{100\mathrm{C}_{\mathrm{case}}} = 1.1 \times 0.0008\Omega = \mathbf{0.88m}\Omega$$

Summarizing What We Did

What I demonstrated is how to use MOSFET RDSon data from the datasheet using the detailed approach. There are lot of assumptions as well during the process. In some cases, I am not doing this long method instead go directly for the worst case for easier analysis. If I pass on worst case, I pass to all conditions. However, there are some scenarios that I need the more realistic value of RDSon for instance to compute the efficiency of the circuit. Based on experienced, using the worst case RDSon to efficiency calculation will give huge error compared to the measured efficiency. The long and detailed approach gives the closer result. If you don't after for this detailed calculation (for example only aiming for stress), you can simply use the ready given worst case RDSon value. You may not mind to derive the difference between the junction and case or ambient temperatures as well if you have huge margin in your design and this simplifies the calculation.

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