Automotive Power Semiconductors

Application Note

Determining the thermal resistance $R_{th(CA)}$ of an application.

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If a power MOSFET in used in an application in which high power losses occur (e.g. linear control), it must be ensured that the losses that are dissipated via the heatsink do not lead to thermal overload of the MOSFET. For this reason it is important to know the thermal resistance R_{th} of the overall system.
The following formula represents the relationship between the power loss P_V and the thermal resistances R_{th} for each application.

$$P_V = \frac{T_{J,\max} - T_{Amb}}{R_{th(JA)}} = \frac{T_{J,\max} - T_{Amb}}{R_{th(JC)} + R_{th(CA)}} \qquad \textbf{(1)}$$

The power loss P_V can be calculated by means of a current measurement in the source/drain current path and multiplication by the on-state resistance $R_{DS(on)}$.

$$P_V = V_{DS} \cdot I_{DS} = I_{DS}^2 \cdot R_{DS(on)} \qquad \textbf{(2)}$$

The ambient temperature T_{Amb} is relatively easy to determine using a thermometer. Alternatively , the worst-case value can be used as a basis for the application. This means that the maximum junction temperature $T_{J,max}$ and the resistance R_{thJA} are still unknown. $T_{J,max}$ is specified in the datasheet in order to protect the device from over-

heating. R_{thJC} is likewise specified in the datasheet. **Equation (1)** therefore has 2 unknowns. On the one hand there is the maximum junction temperature $T_{J,max}$, which is specified by the semiconductor manufacturer and must not be exceeded, and on the other there is the thermal resistance of the application $R_{th(CA)}$.
One approach to a solution is to know the real junction temperature T_J and ensure that this does not exceed the maximum junction temperature $T_{J,max}$. The solution consists in using a TEMPFET . A TEMPFET is designed to turn off at a defined junction temperature $T_{TS(on)}$. This prevents a specific maximum junction temperature $T_{J,max}$ from being exceeded. This behavior is used to determine the $R_{th(CA)}$. With the use of a TEMPFET , **equation (1)** experiences the following modification:

$$P_V = \frac{T_{TS(on)} - T_{Amb}}{R_{th(JA)}} = \frac{T_{TS(on)} - T_{Amb}}{R_{th(JC)} + R_{th(CA)}} \quad \textbf{(3)}$$

This yields the equation for the thermal resistance of the application R_{thCA}:

$$R_{thCA} = \frac{T_{TS(on)} - T_{Amb}}{P_V} - R_{thJC} \quad \textbf{(4)}$$

To make an estimate, it is sufficient to assume the specified datasheet value for R_{thJC}. For a more precise calculation, the resistance R_{thJC} of the TEMPFET and the turn-off temperature $T_{TS(on)}$ should be determined explicitly. The idea is now to increase the power P_V slowly[1] until the TEMPFET switches off. If the TEMPFET is triggered, all the parameters except the thermal resistance of the application R_{thCA} of **equation (4)** are known.
If the thermal resistance of the application is known, it is possible to return to **equation (1)** in order to verify whether the MOSFET is still being operated within the specification.

Example: Analog operation of MOSFETs

[1] In this case, “slowly” means that the thermal transient response is taken into account. See also example.

Maximum power loss in the case of adjustment (same power at the MOSFET as at the load)

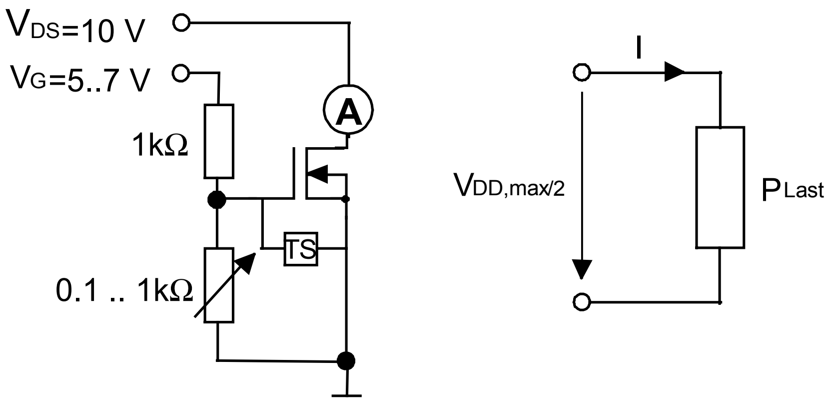

Figure 1: *Example circuit for empirical determination of the thermal system resistance R_{th}*

Procedure:

1) The MOSFET is replaced by a TEMPFET of similar chip area in the application (or on the heatsink), dispensing with the use of the regular drive electronics. See structure of example in ***Figure 1***.

Warning: Active cooling systems must be switched on as the case of normal operation!

2) The load is driven with half the real supply voltage $V_{DD}/2$ (power adjustment).

Important: The ambient temperature must be recorded.

3) A defined drain/source is specified (e.g. V_{DS}=10V; this makes the subsequent calculation easier) and the gate voltage is used to control the power loss generated in the TEMPFET . When this is done, it is important to make sure that the drain current is logged, for this is required for the subsequent power calculation. The system must now be allowed to rest so that it can adjust itself thermally. This can take some time, depending on the size of the heatsink. It is possible to detect from current fluctuations whether the system is thermally adjusted. This can take some time because of the thermal adjustment (depending on heatsink).

4) As of a specific power loss P_V, the TEMPFET reaches its cutout temperature and switches off the system. The thermal resistance can now be calculated using the parameters that were measured immediately before the transistor was actuated.