

Simulation vs. measurement of transient thermal resistance Z_{th} of power modules and its effect on lifetime prediction

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Abstract

Simulation and $V_{CE}(T)$ -measurement based Z_{th} are used to calculate the temperature in an IGBT module after short pulse with high peak losses. Temperature gradient shows significant difference and only simulation based Z_{th} agrees well with the test results from short pulses. Delays between switch off of load current and start of measurement in large power modules have a significant impact on the short-time thermal resistance. The influence of the deviation in Z_{th} on the lifetime prediction has been discussed. Depending of inverter output frequency the deviation in short-time thermal resistance influences the calculated temperature ripple and therefore the predicted lifetime. Making use of Finite Elements simulation to determine the transient thermal resistance Z_{th} ensures the correct calculation of short-time thermal behavior for the lifetime prediction.

1. Introduction

The transient thermal resistance (Z_{th}) of a power module describes a key performance which is on one hand used to estimate the maximum output current for transient loads. On the other hand it can be used to calculate the temperature ripple as with a mission profile and resultant the lifetime of the power module.

When dimensioning a power electronics system, the transient thermal resistance (Z_{th}) of a power module is required to calculate the lifetime [1]. The Z_{th} has a significant influence if different power modules are investigated in the same application, as the heat capacity reduces the temperature ripple for a limited time. [2,3]. A precise knowledge is therefore required to calculate the correct temperature ripple.

2. Determination of transient thermal resistance Z_{th}

2.1. Thermal measurement of Z_{th}

According to e.g. JEDEC standard [4] the measurement of temperature with the $V_{CE}(T)$ method is widely applied. For an IGBT, the temperature-dependent forward voltage drop for a small sense current is measured after heating the device with an load current. The circuit in Fig. 1 is used. To measure the transient temperature behavior the cooling down phase is investigated. A virtual junction temperature which represents the average temperature distribution in the chip is determined [5].

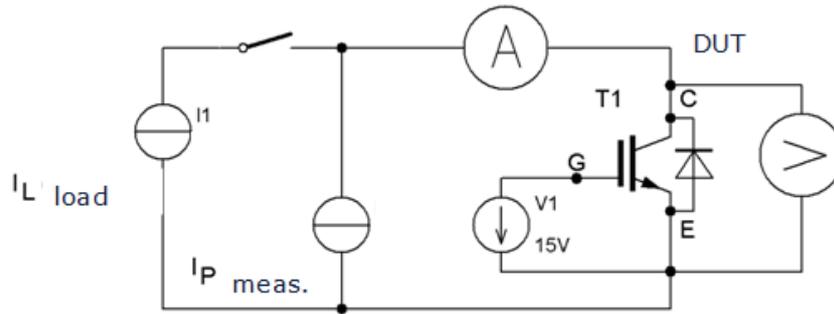


Fig. 1. Measurement setup for Zth

2.2. FEM calculation of Zth

As a second method FEM-Simulation can be used to calculate the Zth. 3D CAD-Data and material properties are used to simulate the transient temperature distribution and extract the average temperature in the chip (Fig.2).

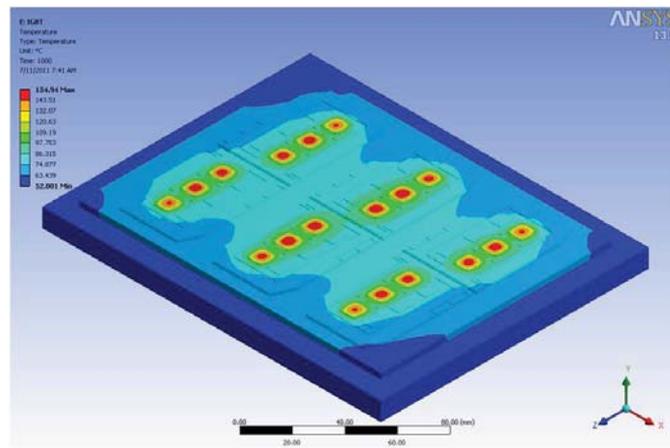


Fig. 2. Temperature distribution as simulation result

3. Differences between measured and simulated Zth

A simulation of the short pulsed test with Zth Foster models derived with simulation and measurement methods is performed. As shown in Fig. 3. Significantly varying temperatures are predicted utilizing these models. The simulation with the Foster model based on simulation results predicts more reasonable results.

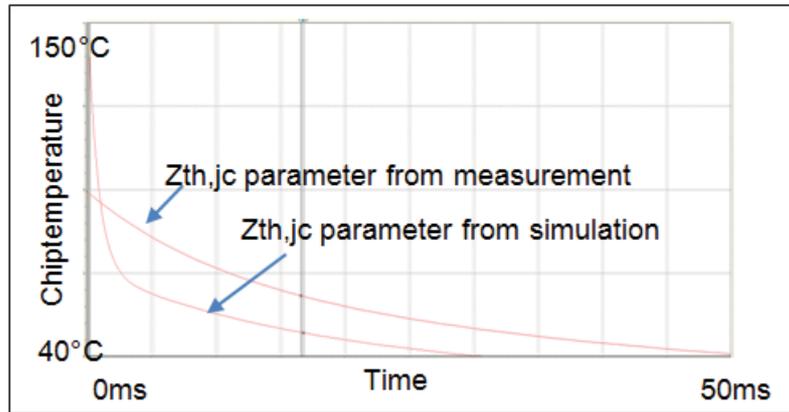


Fig. 3. Comparison of transient temperature after short pulse with high peak losses with different Zth foster models

The calculation results are compared with extrapolated measurement results of the temperature after a short pulse with high peak losses with a single chip from reference [6]. Only the Zth Foster model derived from simulation shows good agreement with the measurement. Better results can be only achieved with direct FEM-Simulation as shown in Fig. 4.

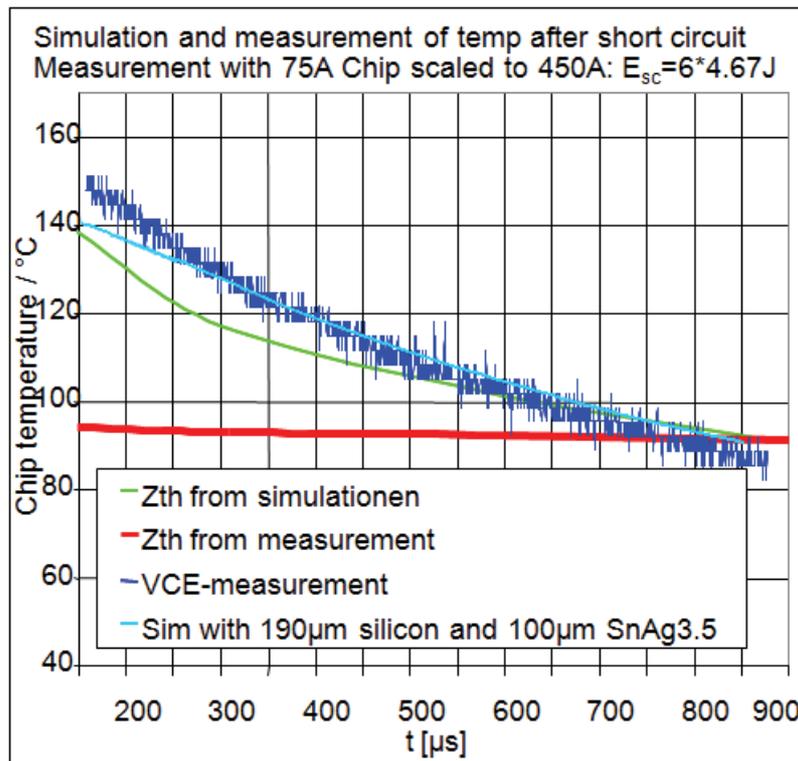


Fig. 4. Comparison of measurement from [6] with FEM-Simulation and calculation results

Simulating the Zth measurement process gives an explanation for the deviations. As shown in Fig. 5, during the measurement process a linear extrapolation for the short time is performed.

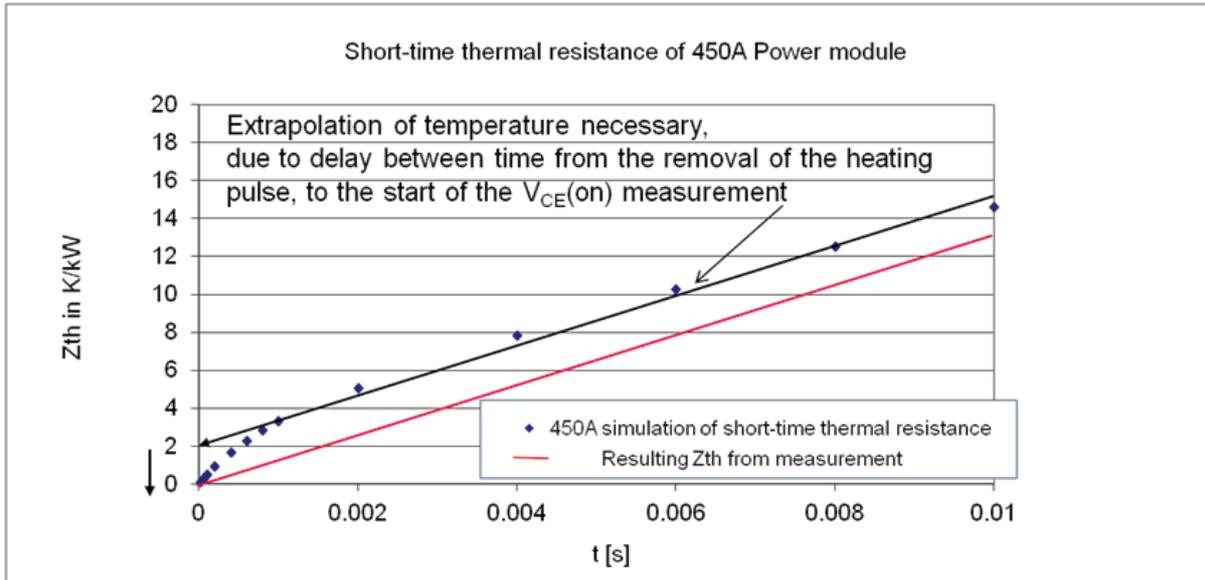


Fig. 5. Comparison of simulation and experiment at short-time thermal resistance: extrapolation to compensate delay in measurement results in negative offset

The simulation result shows a strong change of temperature gradient up to 1ms resulting from varying thermal properties in the stack consisting of silicon, solder and copper in the top part of the stack. The resulting negative offset reduces the $Z_{th,jc}$ in the short-time as shown in Fig. 6.

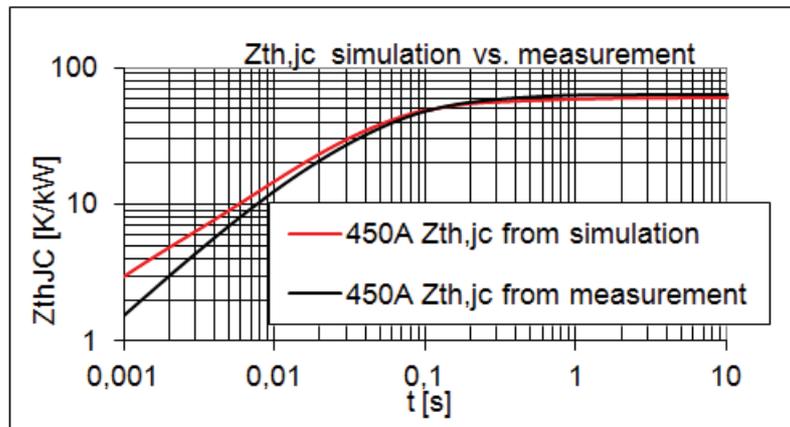


Fig. 6. Comparison of $Z_{th,jc}$ from simulation vs. experiment

To check whether further factors cause deviations between simulation and measurement based $Z_{th,jc}$ curves, the influence of the offset is investigated. In figure 7 the $Z_{th,jc}$ derived from measurement data is corrected with the offset calculated in figure 5.

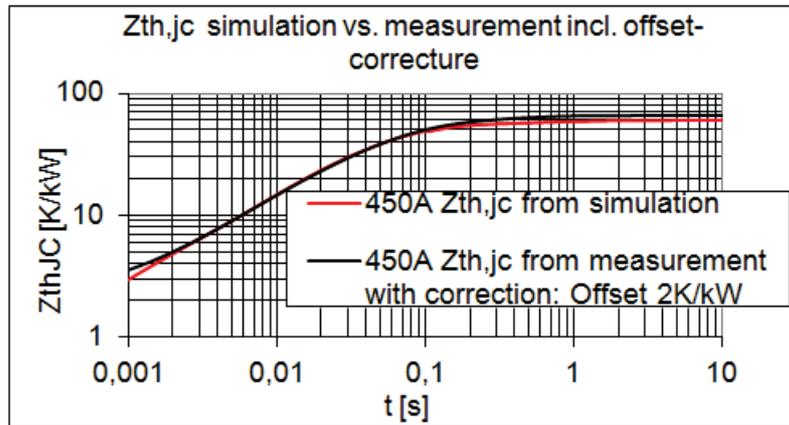


Fig. 7. Comparison of $Z_{th,jc}$ from simulation vs. experiment with offset correction

Correcting the offset this results in good alignment with $Z_{th,jc}$ from simulation. Consequently no further effects are creating deviations between measurement and simulation of the transient thermal behavior.

4. Influence on the temperature ripple and life time

The influence of deviation between Z_{th} from simulation and measurement on the temperature ripple during inverter operation is investigated in two cases. In the first case a typical three phase inverter configuration under the assumption of sinusoidal output currents at inductive loads is considered. The junction temperature therefore oscillates with the output frequency.

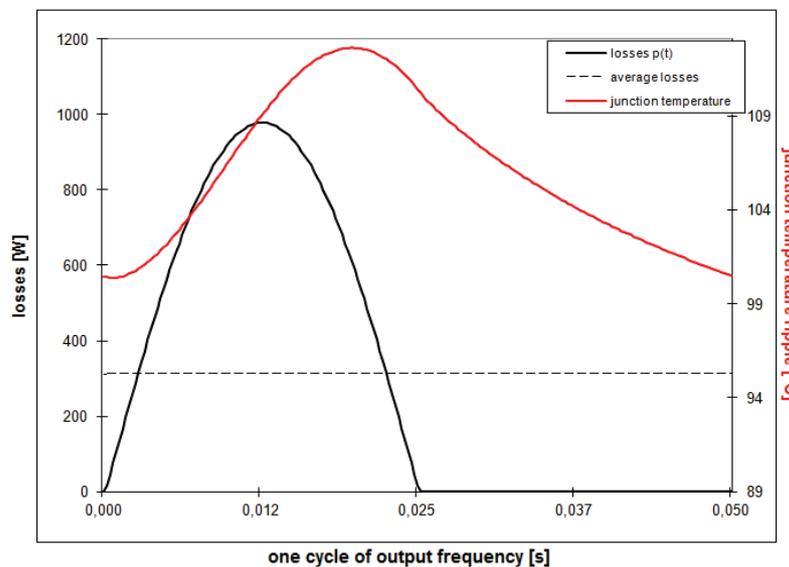


Fig. 8. Sinusoidal power loss shape and resulting junction temperature ripple ΔT (IPOSIM)

Although for selected operation conditions the average losses might be the same, the ripple and therefore the peak junction temperature increases at lower frequency and decreases with higher frequency. The temperature ripple calculation based on Z_{th} from simulation and measurement, performed using IPOSIM tool, is shown in Fig. 9.

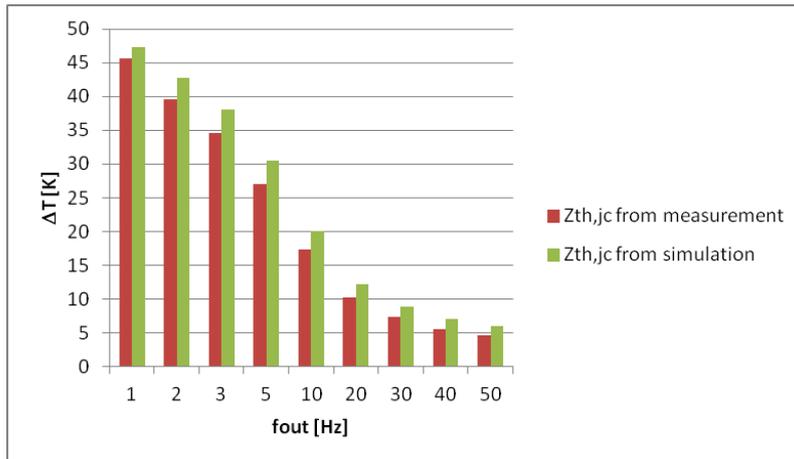


Fig. 9. Temperature ripples ΔT as function of output frequency based on Z_{th} from simulation and measurement

Based on the power cycling curves for IGBT4, a possible number of cycles for the different temperature ripples was calculated, where ΔT less than 10K for frequencies greater than 20Hz were neglected. Calculation results as a ratio of possible cycles calculated based on Z_{th} from simulation to possible cycles calculated based on Z_{th} from measurement are shown in Fig. 10. The life time calculation based on Z_{th} from measurements for frequencies greater than 1Hz seems to be more optimistic. This corresponds, however, to the part of the Z_{th} , which in measurements is inaccurate.

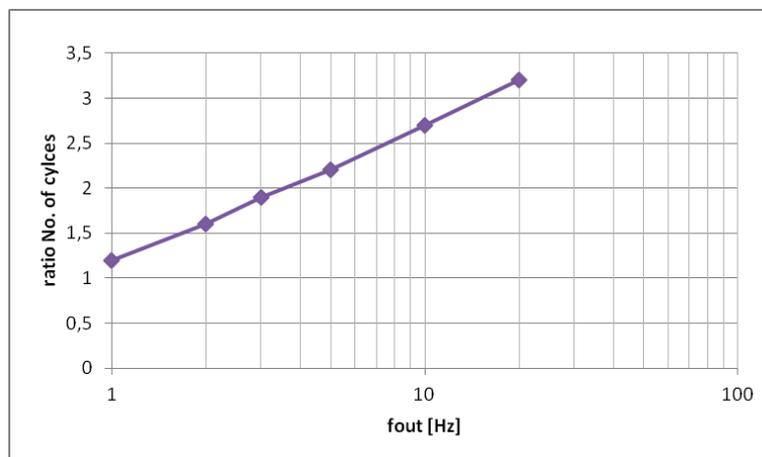


Fig. 10. Ratio of possible cycles calculated based on Z_{th} from measurement to possible cycles calculated based on Z_{th} from simulation

Because for frequencies greater than 20Hz the temperature ripple is negligibly small, in the second case a rectangle load current shape to represent the varying load profile was used. When changing the duration of the pulse (t_{on}) resulting temperature ripples and possible number of power cycles were calculated based on Z_{th} from simulation and measurement.

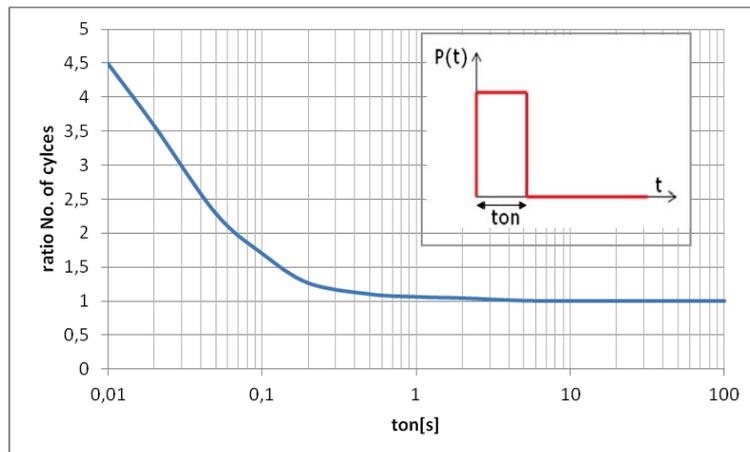


Fig. 11. Ratio of possible power cycles calculated based on Z_{th} from measurement to Z_{th} from simulation

A ratio of possible number of cycles is shown in Fig. 11. In both cases, the lifetime calculation based on Z_{th} from measurements for t_{on} times of less than 1 second (or frequencies greater than 1Hz) look more optimistic. Determining lifetime on the basis of Z_{th} from extrapolated measurements will predict too optimistic results if the mission profile contains a lot of short power pulses with significant amplitude. However, for many common applications relevant load pulses are generally longer than 1 second, which does not affect the calculation error of lifetime.

5. Conclusion

A precise transient thermal resistance (Z_{th}) is required to calculate the temperature ripple as a result of a mission profile, especially for low inverter output frequency. The delay time between removing the heating and starting the V_{CE} measurement and additional noises on the measurement signal requires an extrapolation. This results in a negative offset, when measuring the Z_{th} with the V_{CE} method and applying a linear extrapolation. Making use of Finite Element simulation to determine the transient thermal resistance Z_{th} ensures a correct calculation of short-time thermal behavior for the lifetime prediction.

6. Literature

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