Thermal Analysis of Power MOSFETs Using Rebeca-3D Thermal Modeling Software (From Epsilon Ingenierie) versus Physical Measurements and Possible Extractions

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Abstract

Shrinking semiconductor packages, increasing die densities, process changes, and the requirements for optimizing electro-mechanical assemblies are making sound thermal designs more important than ever. Depending on the application scenario, thermal considerations can be approached from two angles.

If only steady-state values are needed, it is possible to use the thermal resistance values provided in manufacturer datasheets. These include $R_{th(j\text{-}a)}$ for junction to ambient and $R_{th(j\text{-}c)}$ for junction to case. In this case, the average power dissipation in the device can be used to calculate the junction temperature using the simple expression:

$T_j = [P_D \text{ x } R_{th(j\text{-}c)}] – T(\text{case})$

Or

$T_j = [P_D \text{ x } R_{th(j\text{-}a)}] – T(\text{ambient})$

Where T_j is junction temperature and P_D is average power dissipation.

In most high-frequency applications, however, switching transients are inevitable, and they have a significant impact on junction temperature behavior and how it relates to transient power dissipation. These power and temperature excursions are not apparent under steady-state conditions. Under transient conditions, moreover, the semiconductor device has an enhanced power-handling capability. This means that a very high power pulse can be applied for short duration without exceeding the temperature ratings of the device. At this point, transient analysis becomes imperative.

Rebeca-3D, a semi-FEA based software tool, provides the ability to develop a thermal model using detailed device geometry and material characteristics. The tool's versatility allows it to be used to analyze a design in a range of application scenarios.

The simulation yields a thermal image of the device, with the temperature range indicated by a color spectrum. The thermal simulation likewise reveals valuable information about the temperature excursions that may occur in various domains and facets of a given profile.

Using this platform, this paper will discuss actual examples of thermal model development and results. The results will be first validated by comparing with datasheet information and experiments in an application lab.

Following simulation, the platform will be used to extrapolate the measurements done in the application lab. The results will enable development of thermal performance profiles for different packages and for different electrical and assembly conditions. Several examples will be discussed with figures and pictures. The study will compare the results of simulations and tests on actual devices. We will also examine the ability of the software application to derive R_{th} curves for a given package.

The results are expected to show the usefulness of the simulation in practical design cycles.

1. Simulation and Results

Using the Rebeca-3D thermal simulation platform from Epsilon Ingenierie consists of three main steps. The first is generating a detailed 3D geometry of the device and associated PCB assembly. The next step is assigning thermal and electrical properties to the geometrical domain, defining the domain meshing required for simulation settings, and defining boundary conditions according to the operating environment. The last step is to run thermal simulations.

The Vishay Siliconix TSOP-6 package was used to produce the examples provided in this paper. The basic model for the part is shown in Figure 1.

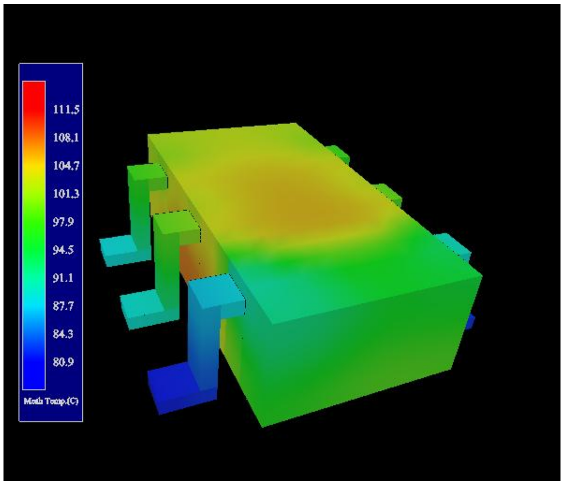

Figure 1. TSOP-6 Basic Model

To validate the thermal model, we mounted a TSOP-6 device on the same standard PCB material used for datasheet characterizations. Typical dimensions for the PCB are 1 in. by 1 in. by 0.062 in. (25 mm by 25 mm by 1.5 mm) using double-sided FR-4 material with a 56-micron, 2-oz layer of 100% copper on both sides. Boundary conditions are 25 °C ambient, PCB assembly in horizontal orientation, and natural convection. Thermal simulation results with 1 W of power dissipation are shown in Figure 2.

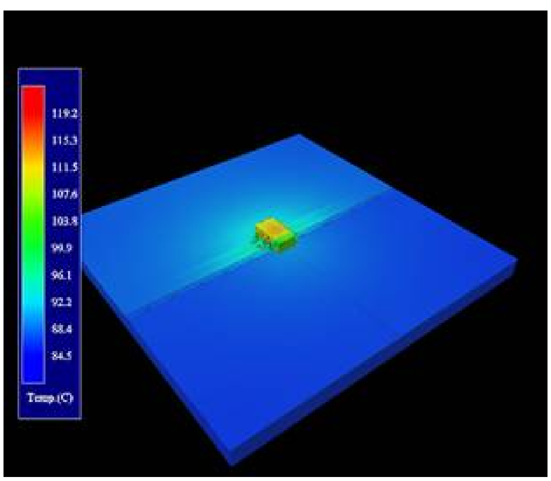

Figure 2. TSOP-6 on 1-in. by 1-in PCB with 100% Copper

Table 1 below compares simulation results with datasheet values [3].

Parameter	Datasheet	Simulation
Unit	°C/W	°C/W
$R_{th(j-a)}$	90 (typ) / 110 (max)	94.2

The $R_{th(j-a)}$ value of 94.2 °C/W obtained in simulation is the difference between the T_j (max) of 119.2 °C and the 25 °C ambient divided by the dissipated power of 1 W. The result is close to the 90 °C/W typical value indicated in datasheet.

So now we have a validated thermal model for TSOP-6 packaged Si3457BDV MOSFET mounted on a standard PCB. The thermal model can be easily modified for different PCB dimensions, materials, layer counts, copper content, and so forth. It can also be adjusted for operating environments and boundary conditions such as ambient temperature, PCB orientation, and air flow, to evaluate device performance under different operating conditions.

In the following simulation examples, the above model is modified for copper content on the top layer. The junction temperature T_j (max) is obtained for a power dissipation of 1 W in each case. The results are tabulated in Table 2 below:

Copper Content Sq. mm	T_j (max) °C
Minimum (rec. pads)	130.5
50	130.7
100	131.4
200	119.3
625 (100%)	119.2

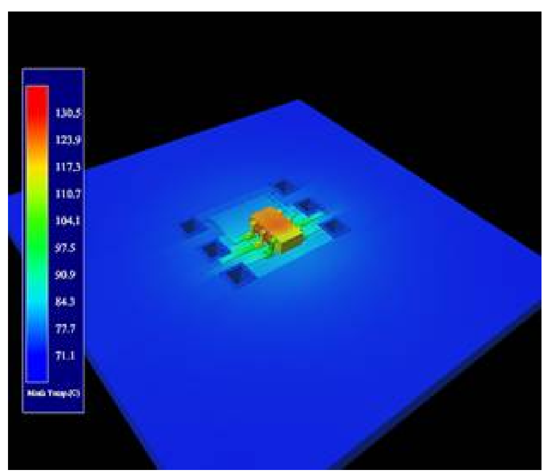

Figure 3. Minimum copper

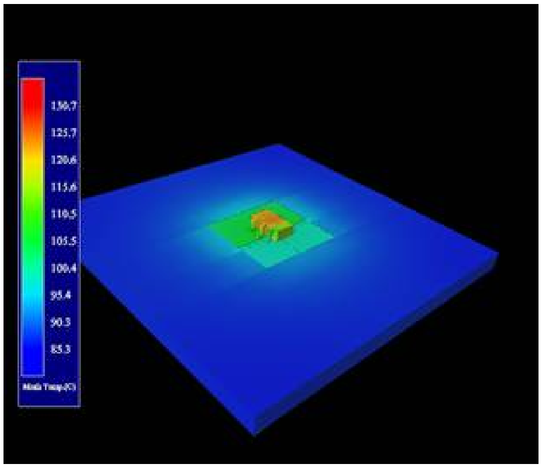

Figure 4. Copper 50 Sq. mm.

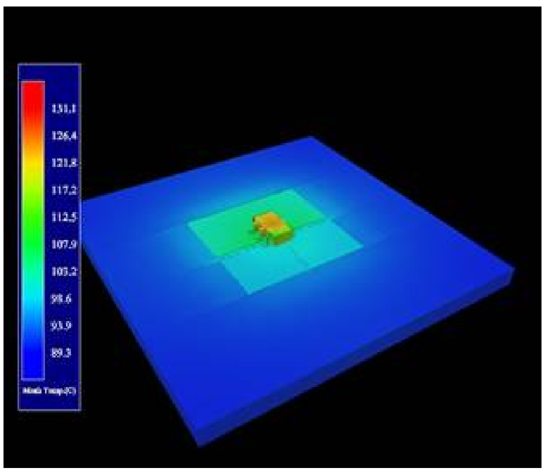

Figure 5. Copper 100 Sq. mm

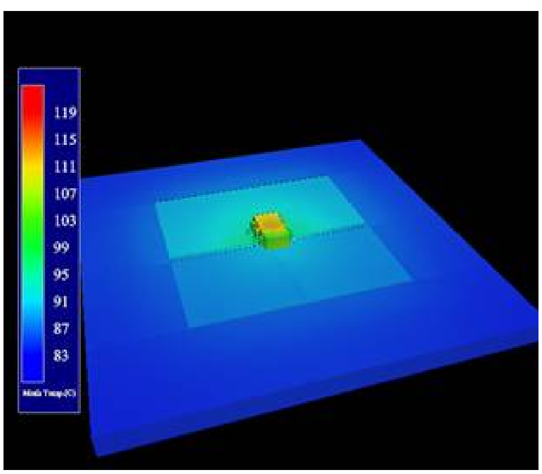

Figure 6. Copper, 200 sq. mm

Next we shall validate these simulations by an application laboratory experiment.

2. Lab Experiments

The experiment set-up is similar to that used for datasheet characterizations. All thermal measurements are carried out by means of a computerized system -- Analysis-Tech [4]. Briefly, the body diode of the MOSFET is calibrated for V_{FD} vs. temperature with a constant current bias. The junction temperature measurement is computed by measurement of V_{FD} with the same bias current.

The basic specifications of the test PCB are the same as that described in the earlier section, but now we will see the effect of using three different types of copper content: (a) 100% copper, (b) minimum copper, and (c) copper spreading the same as the part outline. Figures 7, 8 and 9 show the copper content of the PCB for each case.

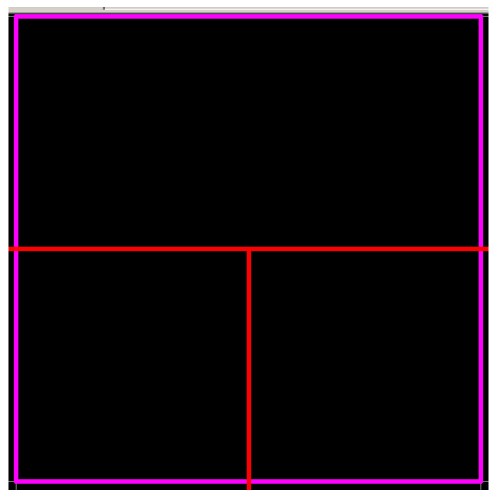

Figure 7. 100% Copper

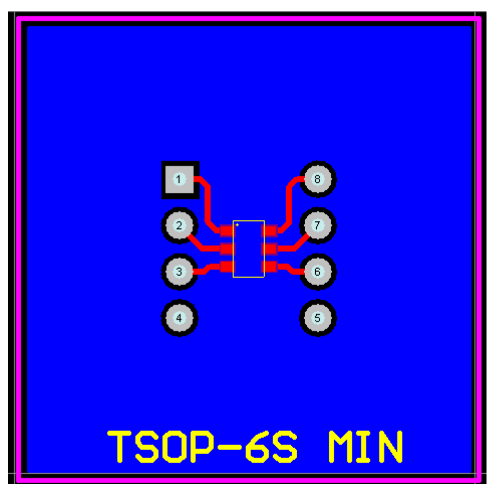

Figure 8. Minimum Copper

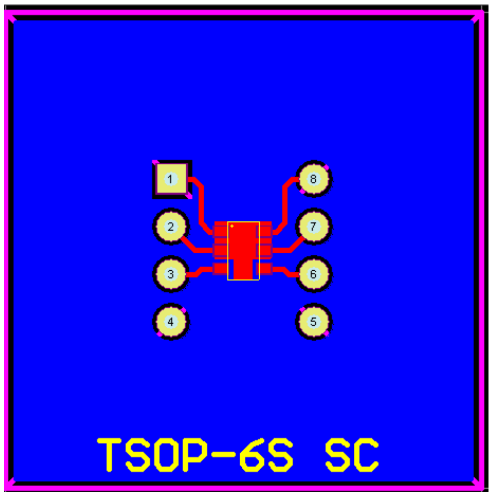

Figure 9. Spreading Copper

Table 3 shows the lab results for three types of PCBs.

PCB Type	T_j (max) ^{O}C
Minimum (rec. pads)	135.6
SC (spreading copper)	128.6
100% Copper (625 sq. mm)	119.3

The validation of Rebeca-3D modeling comes from comparing these results with those from datasheet in Table 1 and Rebeca-3D simulations in Table 2.

3. Extrapolation

A plot with data points used from all three tables (Figure 10) gives an excellent opportunity to extrapolate and predict the part performance on a PCB with any desired percentage value of copper content.

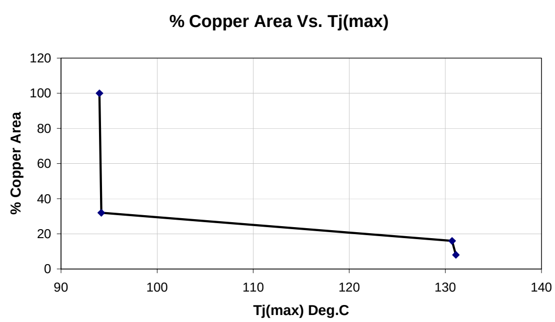

Figure 10

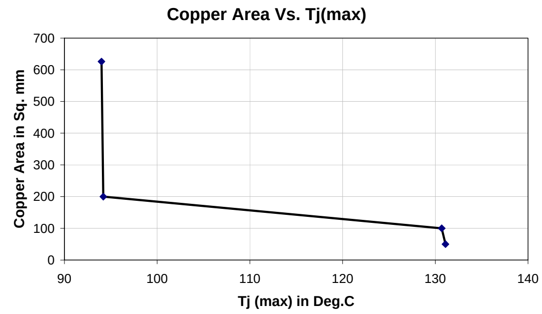

Figure 11

4. Conclusions

Thermal simulation has been shown to be a very useful tool in today's electrical design cycle, in which every component must be optimized for its application environment and where sound thermal analysis is essential.

Taking the experiments described in this paper a step further, various families of curves could be developed using relevant parameters of PCB assemblies to allow designers to quickly evaluate device performance and optimize their designs with the best product for the application while ensuring the safe operation within electrical and thermal specifications.

Acknowledgments

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References

1. "Thermal Model for Power MOSFETs in DC/DC Applications," by Yalcin Bulut and Kandarp Pandya, ESIME 2004.
2. "A Simple Method to Develop Thermal Model for Power MOSFETs" By Wharton McDaniel and Kandarp Pandya, IEEE Semi-Therm 2001.
3. Visit Vishay Siliconix web-site www.Vishy.com for information on the Si3457DV power MOSFET in the TSOP-6.
4. Visit Analysis-Tech web-site: www.AnalysisTech.com