Siemens Digital Industries Software

No more guessing. Why you need to calibrate IC package models

Executive summary

Accurate IC thermal models calibrated against thermal measurement allow IC designers and system integrators to better design for cost and reliability. This whitepaper addresses overcoming barriers with typically time intensive manual iterative methods by using a unique automatic calibration method to achieve higher comparative accuracy by as much as 20 percent in less time. The new method is illustrated using Simcenter Flotherm™ software thermal simulation software and transient thermal measurement data.

Introduction

Siemens PLM Software has been providing solutions for predicting and measuring operating temperatures of IC (integrated circuit) devices for over 25 years. The operating temperature of the IC device is critical to system performance, reliability, and end-user experience. During that time electronics have become more ubiquitous in everyday life and are not only found in controlled environments such as a datacenter or computer chassis. Many people have more computer processing power in their mobile device than a computer workstation did when the first version of Simcenter Flotherm was introduced. In a typical automobile there are dozens of computer controlled electronic systems, many related to driver safety. Electric vehicles (EVs), and hybrid electric vehicles (HEVs) require power electronics modules that operate at high voltage and current. The internet of things (IoT) strives to include electronics in order to connect all objects. As systems of electronics effect nearly all areas of our lives the reliability of electronics has never been more important, and as a result the thermal management of IC operating temperatures never more critical. Thermal design tools have evolved to meet the changing challenges of the products they help engineers to design. In this whitepaper we describe the latest developments.

Importance of accuracy

Whether the electronics are on a circuit board in a server or a mobile device, the best thermal design, or temperature management scheme, requires accurate IC package thermal models. Developing an accurate IC package thermal model has historically been both a time consuming task and one which is of limited value. The value of a calibrated model is limited by the quality of the measurement results on which it is based. Often the measurement data used for calibration does not reflect the in-situ application of the IC device. Given the finite amount of engineering time and limited measurement data the calibration process usually ends with the rationalization that the model calibration is "good enough."

Unfortunately designing products with a 'good enough' mentality leads to a number of issues from the IC vendor, system integrator, through to the end-user. An un-calibrated model leads to overdesign where the model's inaccuracy is recognized, potential underdesign where it is not, resulting in more field failures, and generally longer design cycles due to first physical prototypes performing differently to expectation.

With Simcenter Flotherm V11.1 and Simcenter T3STER Master 2.4™ software the process of calibrating an IC package is automated. This latest advancement in thermal design software means that a process that could easily take an engineer a week of rerunning simulations and still not yield a truly calibrated model can be performed by Simcenter Flotherm to a quantified degree of accuracy, automatically.

Calibration process

Calibrating or validating analytical models hasn't been easy. There are a number of factors that have caused this process to be challenging. There are uncertainties associated with the data that is input such as material properties, the thermal connection between parts of different materials, test setup, and the measurement data. The calibration process involves exercising an analytical model in the areas that are uncertain. To fully understand the implications of each uncertainty during the calibration process has taken significant engineering time, reflection, and interpretation.

A calibration process comparison between typical methodologies vs. the Simcenter Flotherm automated method is shown in figure 1. The typical process involves an interactive and manual approach to calibrating the analytical model against measurement data. After each simulation an engineer must determine how to adjust the model to better match the measurement results. This cycle usually continues until there is no engineering time left. The success of this process is largely dependent on engineering experience and a large time investment.

The Simcenter Flotherm automated calibration process allows the engineer to input the upper and lower bounds of unknown or somewhat known quantities as part of the model definition. Simcenter Flotherm then

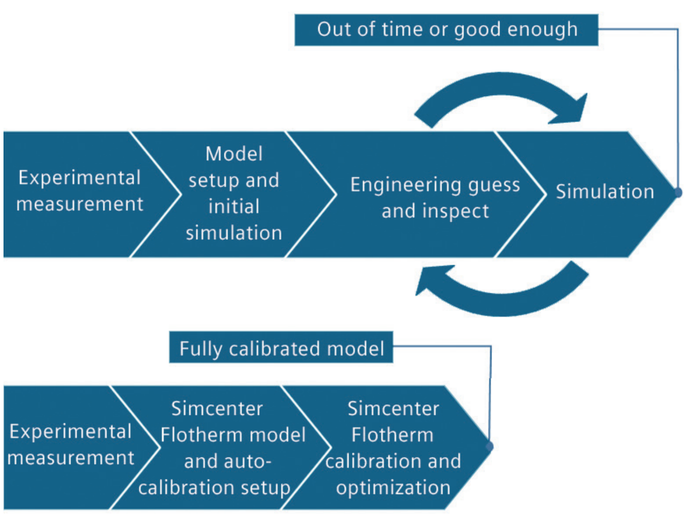

Figure 1: Simcenter Flotherm calibration process comparison vs. typical process.

analyzes the various combination of inputs without additional engineering effort and determines the optimal input values.

The value of Simcenter Flotherm's automated calibration process is that in addition to providing the most accurate analytical model it also requires the least amount of engineering time.

Historical process

Measurement data

A validated or calibrated thermal model can only be as good as the experimental test data it is compared against. Thermal measurements of IC devices generally involves powering the package and measuring the temperature at selected locations in a controlled environment. Typical thermal test environments include still-air chambers, wind tunnels, and cold plates. Two common approaches to IC thermal measurement involve either thermocouples or the electrical test method.

Thermocouples offer a simple and accessible measurement approach but there are caveats to consider. First, the repeatability and accuracy for measuring small temperature differences with thermocouples is difficult, if not impossible, to achieve. Second, there is little understanding of the thermal structure between the measurement points that can be gleaned from this approach. Third, the dynamic response of a thermocouple measurement isn't adequate to accurately capture the transient temperature response of an IC package, and yields no information about internal temperature changes.

Calibrating a thermal model against thermocouple data might match the overall thermal resistance but offers no guarantee that the thermal gradients within the IC are properly resolved. Also, since thermocouples aren't adequate in capturing temperature versus time accurately the calibrated model wouldn't be suitable for transient design scenarios. Essentially the calibrated model is no better than a resistor network.

Quantifying uncertainties

It would not be unreasonable to believe that to create an accurate simulation model it would simply require that all relevant geometric features with appropriate material properties be included. In practice, gathering accurate material data, such as thermal conductivity and heat capacity is time consuming and often ends with some engineering assumptions. Also, as IC packages are assembled from parts of different materials the thermal joint between them is not typically “perfect”. The quality of the thermal joint is not listed in a material data sheet and should be considered during the calibration process.

Given the uncertainty with material properties, material connectivity, and potentially some physical features of the internal IC structure there are a number of design scenarios to be considered during the calibration process. Studying the impact of one variable while multiple variables are changed between designs is very challenging. Reducing the output data to a single best combination of input variables would be difficult to do once, let alone to be considered as part of an efficient design process.

In the end, depending on the amount of time allocated for iterating on an analytical model, the resulting model would yield something determined to be “good enough”.

Resulting model

There are two common distinctions between analytical models: steady state or transient. To develop an IC model for use in transient applications the measurement data must be based on a transient test. If a model is calibrated against transient data it will also be applicable to a steady state application, the opposite is not true. If the model is calibrated using thermocouple data the only guarantee is that the overall temperature rise is consistent but doesn’t offer any insight to the internal temperature gradients. The calibrated model wouldn’t be valid for determining the thermal stress on the package. A model calibrated against thermocouple data is only suited for system design in steady state and is marginally more accurate than the corresponding network model.

Calibration with Simcenter Flotherm V11.1 and Simcenter T3STER

Measurement data

The calibration process with Simcenter Flotherm begins with Simcenter T3STER measurement data. The Simcenter T3STER technology captures the transient response of the IC package without using thermocouples. The Simcenter T3STER measurement is based on the Electrical Test Method, JESD51-1.[1] Simcenter T3STER measures the voltage drop across a temperature-sensitive parameter (TSP) of the device, such as a diode, between two powering conditions. The voltage is related to device temperature through a K Factor calibration of the TSP. Because thermocouples aren’t required, Simcenter T3STER provides a repeatable measurement that is able to accurately capture small temperature differences (0.01°C) between the source and environment. Simcenter T3STER captures transient response of the device under test with a one micro-second measurement resolution in time. Additionally, the Simcenter T3STER technology provides a Structure Function which represents the thermal resistance/capacitance heat flow path and is commonly mapped to physical objects to determine issues with manufacturing processes and identify causes of thermal degradation.[2-6] It’s the industry gold standard for thermal response measurements. A model calibrated against Simcenter T3STER measurement data offers the most accuracy for replicating the internal thermal gradients within an IC package with respect to time.

Quantifying uncertainties

The reality is that there are uncertainties related to material properties and the associated quality of the thermal joint between different materials. There may also be some uncertainty to the heat distribution on the active area of the die. Any calibration process involves studying the impact of these uncertainties. With Simcenter Flotherm V11.1 these “somewhat known” variables are studied and optimized with respect to the transient response provided by the Simcenter T3STER measurement. The engineer specifies the input ranges for each “somewhat known” variable and Simcenter Flotherm does the rest. With Simcenter Flotherm, the process of calibrating an IC device is a systematic and scalable process that provides a calibrated IC package model to a quantified degree of accuracy.

Resulting model

Simcenter T3STER’s measurement results offer the most accurate data to calibrate an IC package model against. If a model is calibrated with Simcenter T3STER measurement results, and associated Structure Function, it can accurately be utilized in scenarios at a steady power or power versus time profile. The model will accurately predict operating temperatures as part of a system design as well as the internal temperature gradients useful for thermal stress predictions.

Benefits

Historically the two biggest bottlenecks to developing truly calibrated thermal models have been capturing appropriate measurement results and the engineering time associated with quantifying the various uncertainties related to the physical properties of the device. A Simcenter T3STER measurement with its resulting Structure Function provides a comprehensive understanding of the thermal response of an IC device. Simcenter Flotherm automates the calibration process against the Structure Function of the device. Risks associated with using uncalibrated models include reliability, longer design cycles, under and over design. The calibrated model has specific benefits in various areas of Electronics thermal design.

Better system design

A calibrated detailed model provides the greatest accuracy for the system designer. This is true for thermal design at a worst case power condition or based on a power versus time scenario. Consider the transient response of an IGBT to a waveform shown in figure 2. An uncalibrated model will either over predict temperature, which will lead to over design, or under predict temperature which will directly affect reliability. Worse, for arbitrary power profiles, the effect is cumulative as transient results depend on the temperature history to date. The inherent risk is that as the investigation continues eventually the simulation will contain results that are completely meaningless and the engineer bases design decisions on bad data. If the risk to reliability is mitigated later on during system testing this will lead to longer design cycles. With a calibrated thermal model the design time is minimized as more design occurs earlier in the process.

A calibrated model will also accurately predict the temperature response to less understood power profiles as would occur in mobile devices. A mobile device is a tightly integrated system where designing for many use cases is imperative to maintain system response and end-user experience. Understanding the dynamic behavior of every component in a mobile device is vital to developing a proper temperature control scheme.

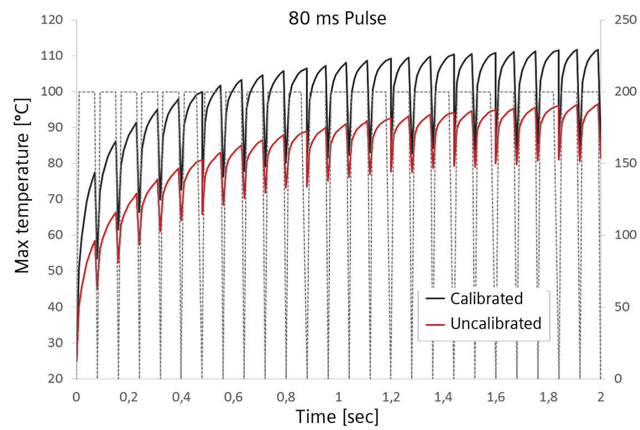

Figure 2 :80ms pulse temperature reponses.

Better IC package design

Two of the most significant thermal design concerns of the IC package designer are related to thermal stress and reliability. The Simcenter Flotherm calibration process uses the Simcenter T3STER Structure Function which means that the constituent thermal resistance and capacitance values are calibrated. The resulting Simcenter Flotherm model will provide the most accurate temperature gradient map of the IC device to predict thermal stresses within the IC package. Consider the temperature gradients after a single power pulse of a “best guess” or “good enough” thermal model (upper image) compared to a calibrated model (lower image), shown in figure 3. The temperature gradients of the

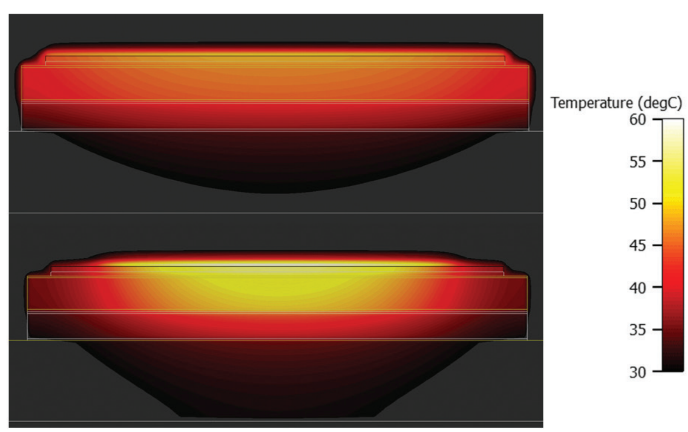

Figure 3: Temperature contour comparison: best guess (upper) vs. calibrated (lower).

non-calibrated model will lead to false thermal stress predictions and ultimately the reliability of the device.

The calibrated model would also provide value in understanding the thermal degradation of a part either due to cycling or a manufacturing defect. In this scenario, the structure function from the cycled part would be calibrated to determine the area in the device that has degraded, for instance in the die attach or solder joint area. Similarly, the same process could be used for understanding defects during the QA process.

Certified supply chain

Calibration with Simcenter Flotherm and Simcenter T3STER provide an accurate, repeatable, and scalable solution for calibrating an IC device for a number of different use cases. The calibrated model has value to suppliers for their internal design needs but also to facilitate the supply chain. A certified model derived from Simcenter Flotherm's automated process using Simcenter T3STER structure function data would provide confidence to the system integrator of the accuracy of the provided model. Rather than the vendor justifying to their customer their internal design processes, a known and established process could be used. The vendor can provide either a validated detailed model or compact thermal model derived from the calibrated model. Either model would provide the most accurate model to the system integrator.

Conclusion

Developing accurate detailed IC package models has been constrained by the finite amount of engineering time and the quality of measurement results. As a result, the calibration process usually has ended with the rationalization that the model calibration is "good enough". An un-calibrated model leads to overdesign, more field failures, and longer design cycles. With Simcenter Flotherm and Simcenter T3STER engineering time is minimized, and the calibration optimized against the most accurate measurement results.

Simcenter Flotherm and Simcenter T3STER provide a repeatable, accurate, and scalable solution to a process that has historically been both time consuming and insufficient. Never before has there been an automated process for calibrating an IC model against thermal measurement data. A detailed IC model calibrated with Simcenter Flotherm will allow both IC designers and system integrators to shorten design cycles and improve their design.

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