HOT OR NOT? AN INTRODUCTION TO

ELECTRICAL THERMAL CO-DESIGN

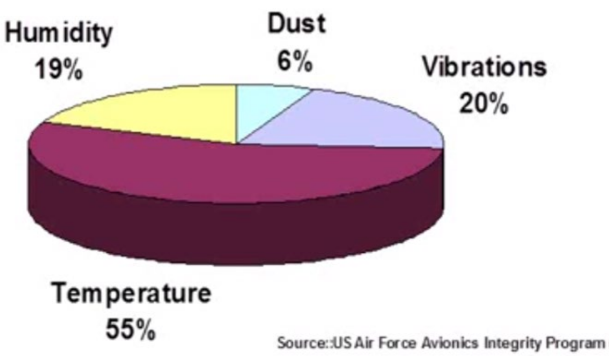
EMA Design Automation®

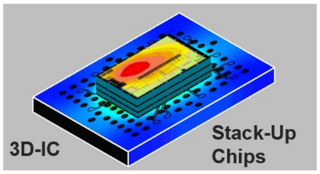
HEAT TRANSFER
IS NOT A ONE-WAY STREET

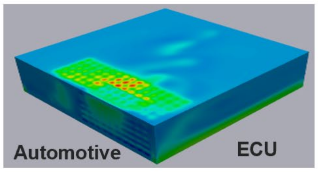
Traditionally, thermal analysis and management is thought of as a mechanical problem.

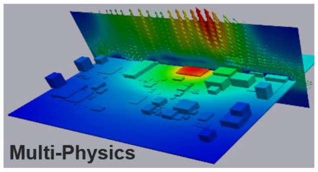
However, modern electronic products are highly susceptible to electronic thermal issues. The electronics are often both the cause of thermal issues and the victim of overheating if temperature profiles exceed specifications. Indeed, over 50% of IC failures are related to thermal issues. Many current methods for analyzing thermal effects however, are often unable to accurately predict the electronic feedback of the device current, leaving an incomplete model of thermal performance. Over-simplified models, missed issues, and over-designed margins are all results of incomplete data capture, and design issues such as hotspots and current clustering are likely to be missed. As such, the more accurate the electrical thermal model, the more reliable the product is both from an electrical and mechanical standpoint.

It’s important to realize thermal issues are an electrical problem that needs to be addressed. This e-book will discuss why thermal analysis needs to be performed in the electrical domain and highlight several nuances, pitfalls, and challenges of thermal design and how to best navigate them.









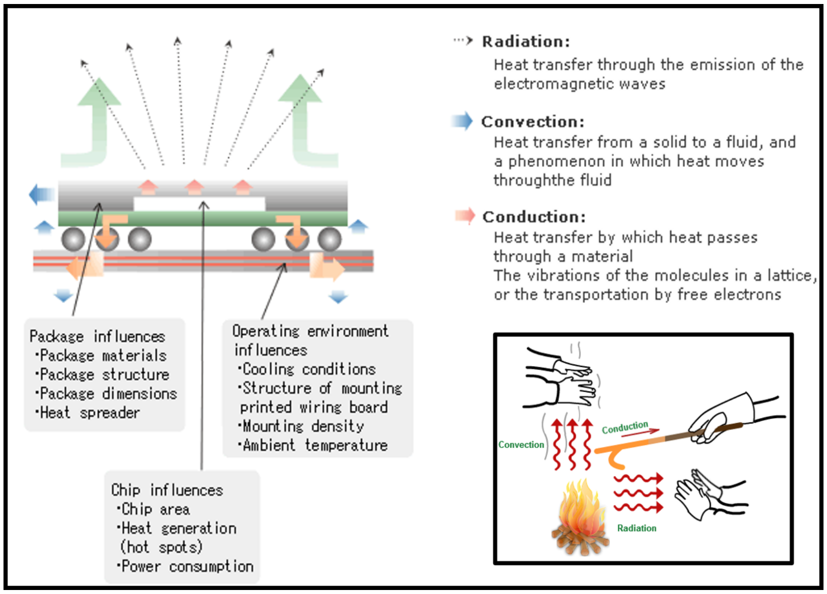
So, what does this mean for design engineers?

Electrical engineers know the most about their PCB models and therefore are responsible if they fail. When it comes to thermal issues, most models focus on the heat created by components but overlook issues with two other main aspects: the heat intake from adjacent components, and the heat transferred between those components.

REMEMBERING FOUNDATIONS
WHY DOES THERMAL MATTER?

The *law of conservation of energy* states that energy can neither be created nor destroyed- only converted from one form to another.

Knowing the basics of thermal will help you gain confidence in the tools at your disposal. More importantly, it allows for a thorough understanding of the benefits and consequences of your design decisions.



There are three modes of heat transfer, and each have unique attributes:

Radiation: Heat transfer through the emission of the electromagnetic waves
Convection: Transfer from a solid to a fluid state, where it continually moves through the fluid
Conduction: Tansfer in passing through a material, by the vibrations of the molecules in a lattice, or the transportation by free electrons

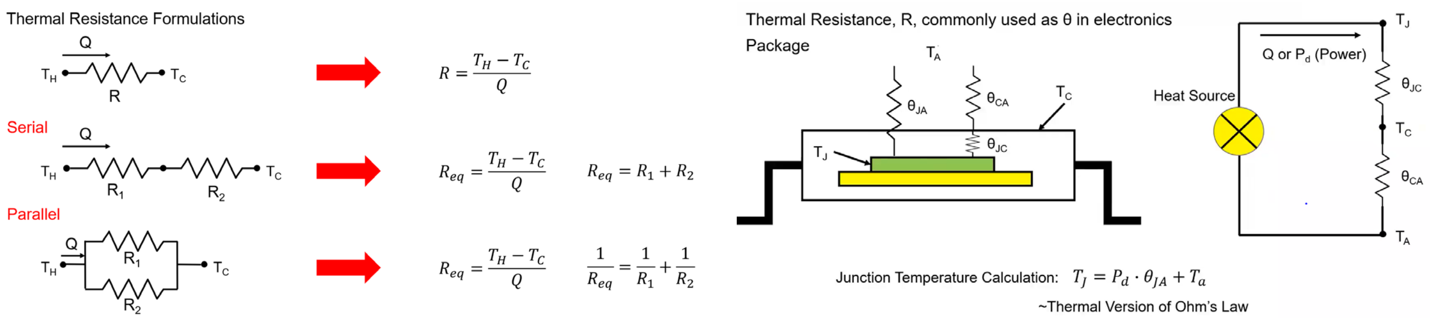
While these concepts may seem very basic and high-level, they can be easily forgotten in the frenzied process of the PCB design cycle. Everything from the space within the enclosure to the distance between pins and components can conduct unwanted heat. This leaves little room to escape if proper thermal resistance, heat sinks, or ventilation are not considered. Remember, even air itself can be conductive. Keeping this basic principle in mind will save you many issues down the road.

TJ MAX

HITTING THE LIMIT

Heat flows from hot to cold, but it can be interrupted along the way.

In both electrical and thermal resistance, the resistance can be serial or parallel in addition to the basic flow. It is possible to calculate a thermal resistance using equations, such as the **Junction Temperature Calculation** (a thermal version of Ohm's Law). This calculation will give you working numbers to use for your TJ max limit.



What is junction temperature?

Simply put, it is the highest operating temperature of the actual semiconductor in an electronic device. TJ max is the maximum limit of this temperature. Most often, you will see this terminology in relation to laptop core processors such as Intel, though it is highly important for CPUs in other electronic devices as well, such as desktop computers, video game consoles, and smartphones. As a rule of thumb, you should keep your device 25 degrees below this max to avoid critical failure. This is because if the CPU reaches the TJ max, it will throttle performance or shut down completely.

That said, there is no set ideal temperature at which your board should run; it can vary depending on the industry, the manufacturer, and the complexity of the system. While most electronic devices are rated to an absolute maximum of 150 C, the commercial, industrial, automotive, military, and medical fields will have specific guidelines and tolerances for safety and optimal operating temperatures based on the product. Be sure to gather this information before you design.

KEEP IT COOL
HEAT SINKS AND VENTILATION

Heat sinks are used to keep temperatures in check and within guidelines.

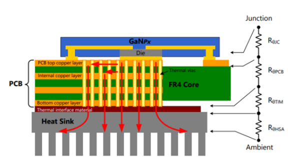
Applied when the TJ max has potential to be surpassed, heat sinks are devices put in place to disperse heat from surrounding objects. Some components require their own, separate mini heat sink, as they generate a lot of heat on their own. Heat sinks have a thermal conductor to carry heat away from the CPU into fins. These fins provide a large surface area for the heat to dissipate throughout the rest of the computer, cooling both the sink and processor.

Heat sinks can be added to a device by clip-on, Z-clip, or pushpin attachments. Each will depend on your available space on or around the PCB. Keep in mind the heat within a sink needs to spread, so be sure to give ample space within the fins on the sink itself. Thermal interface materials (TIM) such as grease, gel, tape, pads, and thermally conductive adhesive should be used between two parts to reduce interfacial thermal resistance.

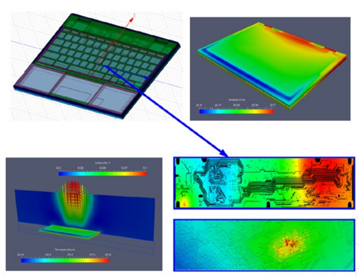
Heat sink attached to the device case

$$T_J = P_d \cdot \theta_{JA} + T_a$$

Heat sink attached to the device exposed pad of TO-220



Heat sink attached to the PCB



Converting heat to a fluid medium can lower a devices’ temperature.

Laptops cannot use a liquid coolant, so the structure of fans and fan vents within the case enclosure are critical. They give the heat a chance to properly ventilate out of the system via forced air and increase the overall efficiency of the heat sink. As a case study, earlier Macbook Pro laptop models have been inefficient in their cooling. The fan outtake was placed in the fold of the device at such an angle that the hot air had difficulty escaping. Coupled with high heat from the battery, many of these models overheated and lost operating efficiency, while others caught fire. As a result of these failures, subsequent models have included better forms of ventilation and more strict Tj max guidelines. Design engineers must take stories like this to heart and learn from them to push the medium of electrical engineering forward.

The Verge

Apple recalls older 15-inch MacBook Pros because the batteries could catch fire

Apple recalls older 15-inch MacBook Pros because the batteries could catch fire ... Overheating batteries are no laughing matter, so this may be urgent: ... that third-generation MacBook Pro between 2012 and 2018, so

Jun 20, 2019

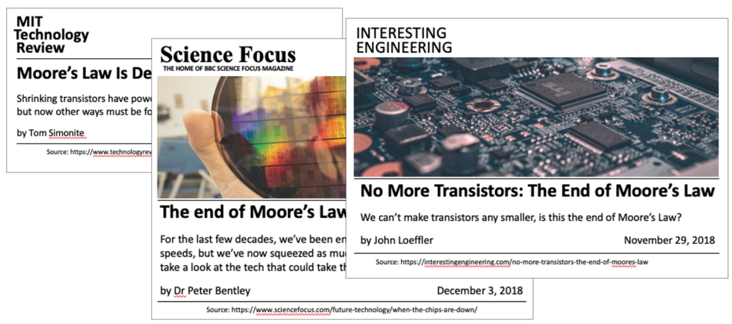
CONSIDER THE FOLLOWING:
MOORE'S LAW

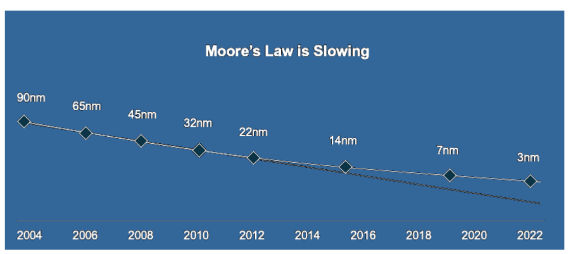
Theorized in 1965, Moore's Law states:

The number of transistors on a microchip doubles every two years, the cost of computers is halved, and the growth of microprocessors is exponential.

While the truth of this statement is holding for the moment, it is starting to hit the fiscal limit.

Gordon Moore – Moore's Law (1965)
Co-founder, Intel Corporation





As the number of components grows on ever-smaller boards, we start to see thermal issues (like current leak) arise.

As a result, Dr. Andrew Grove (Intel, 2002) and Dr. Bernie Meyerson (IBM,2004) predicted the device "power cliff". Since then, engineers have been fighting against this power cliff with innovations such as high-k gate dielectric, multi-gate devices, multi-core architectures, SOI, and more. While researchers continue to drive advances in material science, the enhancements of chip performance must not only focus on an increased clock rate or power—they must also focus on thermal limits.

General guidelines address these issues, like separating high-power dissipating components from each other, as well as from temperature-sensitive components. Maximizing heat spread and the number and thickness of copper ground layers will also help reduce problems. Additionally, adding more power and ground vias will also help the energy flow, minimizing hot spots where energy accumulates and does not have a path out. Being aware of these guidelines and adhering to them provide the foundations needed to build the optimal design.

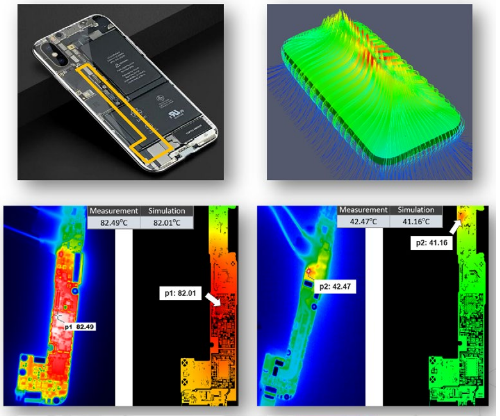
THERMAL–AWARE DESIGN

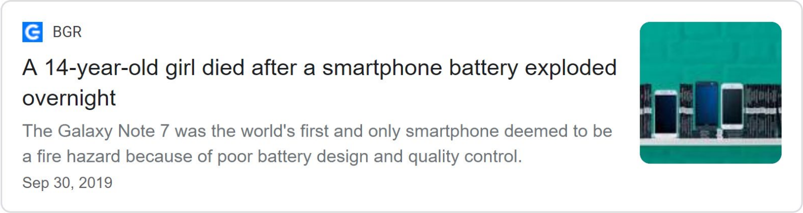
A HOT TOPIC

The thermal dynamics present inside a design are often interconnected in a web, where one element may impact another.

For one, we know the system electrical performance depends on the thermal profile. System resistance and power dissipation are both affected by temperature, and in turn impact functionality and device reliability. To follow this logic, the system thermal profile itself depends on electrical performance. An elevated electrical resistance will introduce an additional heat source. Likewise, adverse hotspots can arise due to local high-current surges. These interdependencies can easily spiral out of hand when not checked, resulting in thermal runaway and causing critical failure. Therefore, transient simulation becomes critical in successful electronic design.

Handheld devices like smart phones require special attention regarding thermal, as overheating and device failure could result in a serious injury to the consumer. This scenario unfortunately happened with the infamous 2016 Samsung Galaxy Note 7 smartphones, which caught fire and even exploded in several cases. Samsung recalled 2.5 million phones, and upon investigation, found the batteries were crimping and malfunctioning due to too-tight enclosure parameters.



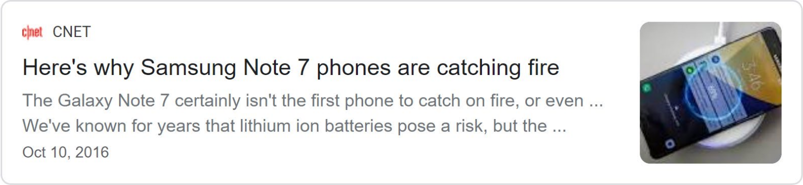


BGR

A 14-year-old girl died after a smartphone battery exploded overnight

The Galaxy Note 7 was the world's first and only smartphone deemed to be a fire hazard because of poor battery design and quality control.

Sep 30, 2019



CNET

Here's why Samsung Note 7 phones are catching fire

The Galaxy Note 7 certainly isn't the first phone to catch on fire, or even ... We've known for years that lithium ion batteries pose a risk, but the ...

Oct 10, 2016

The grim, real-world consequences of a thermal failure underscore the importance of thorough checking in a design.

Time-varying power profiles will account for multiple operational modes, such as the power levels used when a phone is in use versus when it is not. These profiles may respond to fine-grained electrical switching time, to allow for proper heat transference and cooling.

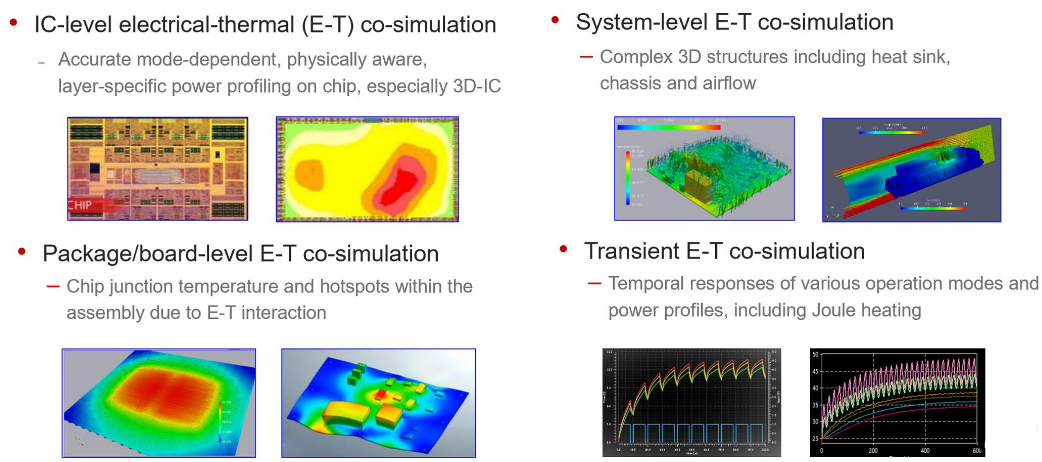
SYSTEM THERMAL ANALYSIS

CO-SIMULATION

Most thermal analysis is done at the mechanical or system level, without the ability to accurately model the electrical impacts.

This has proven adequate in the past but as the examples presented here show, electrical system complexity and lower margin for error are making it so pure mechanical thermal analysis isn't able to fully identify potential problems (or if they do, it often happens very late in the electrical system design cycle). This is where Thermal Electrical co-simulation comes into play.

From both physical and methodology points of view, you need the ability to foresee how thermal changes will impact your design before it goes to manufacturing. To do this, there are several types of co-simulation, and each has its own set of benefits and challenges.



Utilizing co-simulation gives you a highly accurate view into the thermal inner-workings of your design.

As designs become more complex, traditional thermal flows struggle to provide the level of detail needed to properly characterize the electrical system and the resulting thermal profiles together. Taking a closer look into your design will provide the benefit of insight to any future problems that may occur.

CO-SIMULATION
A CLOSER LOOK

Let's take a closer look at the different types of co-simulation:

• **IC-level electrical co-thermal (E-T) co-simulation** is a good way to zoom in and see what is happening electrically within a very small chip. The mode-dependent, physically aware, and layer-specific profiling on the chip allows you to refine even the smallest nuances, especially in a 3D-IC model or TSV configuration.

• **Package/board-level E-T co-simulation** is achieved on a larger scale, across the whole board. This view gives a visual to chip junction temperature and hotspots within the assembly due to E-T interaction, rendered in either 2D layered or 3D structures. Both finite element analysis (FEA+) and computational fluid dynamics (CFD) techniques can be used for both steady-state and transient simulation.

• **Transient E-T co-simulation** shows temporal responses of various operation modes and power profiles of the device, including Joule heating. This provides insight into temperature changes or power variations as the device is in use, such as when we watch video or listen to audio on a cell phone. Realizing the relationship between these events help optimize performance and safety.

• **System-level E-T co-simulation** zooms out even further, to look at the entire assembly and heat flows therein. This view can be seen in a traditional coding arena and encapsulates both FEA and CFD techniques. This helps designers understand the relationships between the various components of the complex 3D structure. These components include the locations of heat sinks, the structure of the enclosure in relation to the PCB, and potential airflow and heat dissipation as it would happen between them.

Understanding how various temperature flows can impact the final product functionality is fundamental to a top-quality user experience.

With detailed early analysis, changes can also easily be made before the product moves to the prototyping or manufacturing stage, shortening time-to-market and allowing for increased productivity.

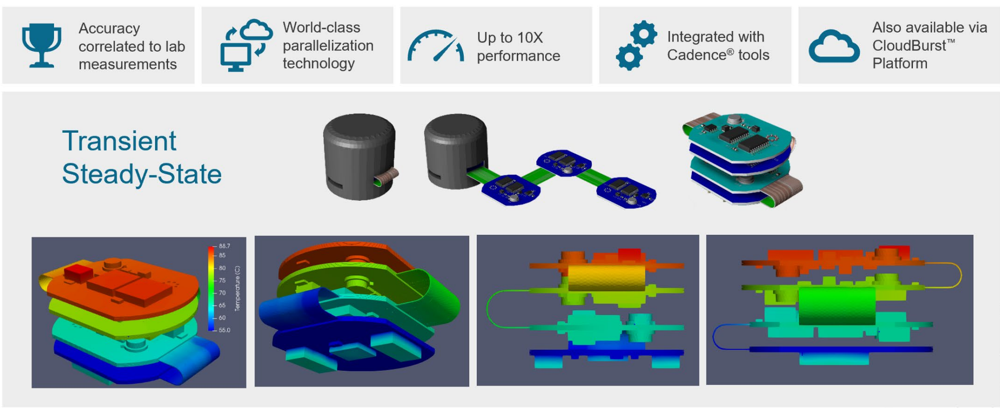
CELSIUS THERMAL SOLVER

A UNIQUE ELECTRICAL/THERMAL SOLUTION

It is no secret that electronic design teams are becoming more impacted by thermal issues than ever before.

There is an intrinsic relationship between electrical and thermal performance in the electronics world: the more copper you have, the lower the thermal resistance of the junction temperature to transfer to the ambient air. Considering thermal challenges and benefits at the design stage in context of your design shortens the design cycle with a right-first-time approach to thermal dynamics.

Celsius Thermal Solver provides a complete electrical-thermal co-simulation solution



This is why Cadence® created the Celsius™ thermal solver under the Cadence® PCB and System Analysis platform.

Celsius ™ is a system electrical and thermal analysis tool meant to equip electrical engineers with the ability to perform electrical co-simulation. Engineers can load complex systems, like laptop configurations, within the tool for full transparency. The heat flow from chips, board, and package to fans and heat sinks are visible and can be tested in steady-state and transient electro-thermal co-simulation analysis. Celsius ™ also leverages a massively parallelized matrix solver, has liner scalability without losing accuracy, and provides seamless integration with Cadence ® Design Platforms, including Virtuoso ™ and Allegro ™ technology.

See more info on Cadence ® Celsius ™ Thermal Solver, or contact us at info@ema-eda.com.

EMA Design Automation®