

# THE HEAT IS ON

Toshiba improves product reliability and decreases development time through electromagnetic–thermal–stress coupling.

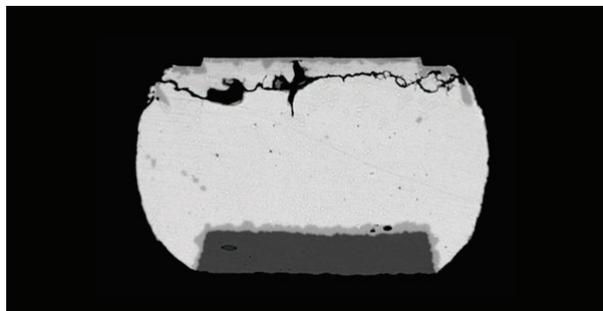
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To meet current time-to-market demands, designers must shorten design cycles and eliminate repetition of design steps, called “backtracking.” A critical area of product design is improving reliability and product lifetime under real-world conditions. Heat damage to components, subsystems and systems can reduce product longevity.

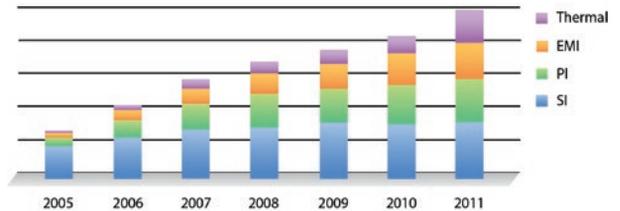
To address both of these challenges, Toshiba employs more and more computer-aided engineering analysis, with thermal analysis showing the sharpest increase in growth over the past six years.

Thermal analysis has always been important, but, due to new trends and design constraints, the latest designs experience more heat issues. For instance, decreasing product size to improve usability and decrease costs makes it more important to plan for and eliminate heat across all electronic product segments. In addition, to suppress noise or improve aesthetics, engineers tend to design fanless or enclosed structures. To provide higher-speed operation or increased functionality, today’s electronics products consequently consume more power. Finally, the use of multicore integrated circuits (ICs) can generate intense heat as well as require higher current on printed circuit boards.

All of these conditions have made electronic design more difficult, increasing the demand for robust, accurate thermal analysis as early in the design process as possible. Simultaneously, the need for accurate overall systems analysis during the simulation process has grown. Without a robust preliminary study, problems due to thermal stresses can be verified only in the post-production phase, such as during the power cycle test, which requires significant backtracking to adjust and rework designs.



▲ Solder cracking due to thermal stresses



▲ In recent years, the engineering team at Toshiba has received more and more requests for thermal (as well as other) types of analysis.

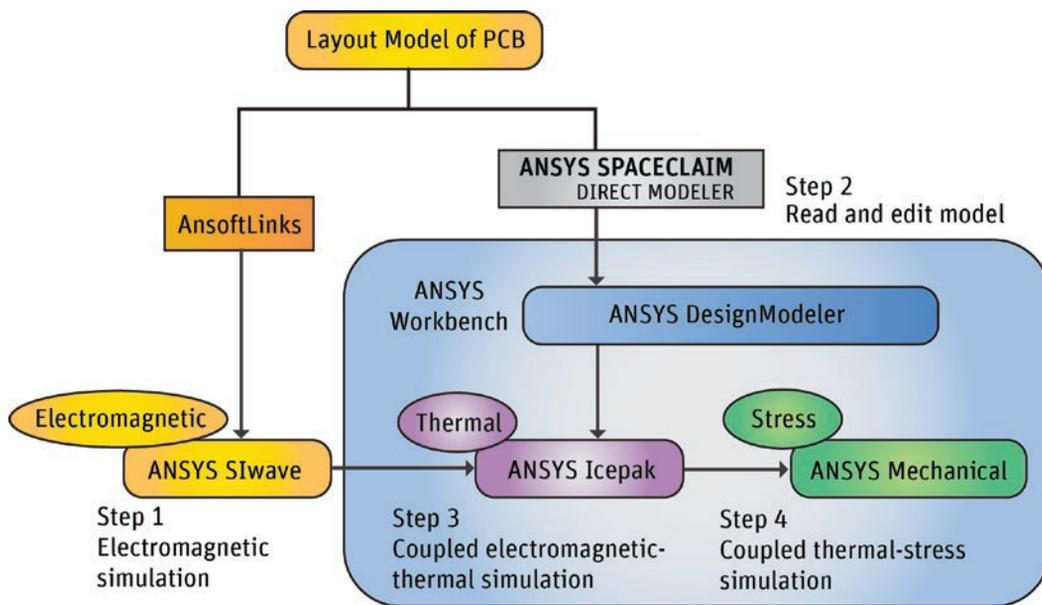
What is needed is an optimized design process that uses a coupled electromagnetic–thermal–stress simulation in the early stages of design.

## IDENTIFYING THERMAL EFFECTS

To address onboard thermal issues, thermal analysis is necessary. Furthermore, engineers must couple electromagnetic and thermal analysis to perform an accurate study of heat in the concept and layout design phases. However, even if temperature specifications are met, other types of thermal issues may remain. For instance, rising temperatures can lead to thermal stresses that cause solder cracking, which prevents transmission of electromagnetic signals. Other thermal stresses can damage the product, shorten its life, and lead to product failure.

A circuit board often comprises several different materials, each of which has a specific expansion/contraction behavior. Thermal stresses occur when the length and volume of expansion/contraction of the various materials vary. To extend a product’s life, the R&D team must determine the point at which thermal stress occurs, and then optimize the design to avoid this condition.

An ideal concept and layout design process results in a robust design that does not experience any problems in terms of electricity, heat or stress. Specifically, the design should satisfy the electromagnetic and temperature specifications and be free of cracks. Toshiba’s goal was to conduct a study of design optimization methodology that included a set of coupled electromagnetic–thermal–stress simulations. If this study is successful, it will enable Toshiba to use this method early in the design cycle to help design for product integrity.



▲ Using a number of ANSYS products all within the ANSYS Workbench environment, it is possible to conduct a coupled electromagnetic–thermal–stress simulation to predict product lifetime.

## COUPLED SIMULATION

Coupled simulation recognizes that each condition, such as electricity or heat, mutually affects the other. So, instead of studying just the thermal effect caused by electric current, engineers must look into the effect of heating on the current flow in a design. For example, when electricity causes heat to be generated, this is a coupled phenomenon, and simulation of this is a coupled simulation. If the simulation also considers how the resulting heat affects the electricity, this is a two-way coupled simulation. Otherwise, it is a one-way coupled simulation.

Coupled simulation provides improved real-world accuracy, and it also increases simulation efficiency. In a traditional electromagnetic simulation, the engineer obtains a model, edits it, inputs the simulation conditions and conducts the simulation. Then, this entire process is repeated separately for a thermal simulation, and repeated again for a stress simulation. Consider the ideal scenario of a coupled simulation: A common model is obtained and edited in a single workflow,

which improves efficiency. In reality, however, engineers sometimes have to use different data for the various types of simulations and cannot always use a common model, which makes the coupled simulation process a bit more complex.

## ELECTROMAGNETIC-THERMAL-STRESS SIMULATION SETUP

Toshiba’s electromagnetic–thermal–stress simulation followed a specific workflow:

- Step 1:** Electromagnetic simulation
- Step 2:** Model creation
- Step 3:** Coupled electromagnetic–thermal simulation
- Step 4:** Coupled thermal–stress simulation

In step 1 (electromagnetic simulation), an ANF file is created from the PCB’s CAD data and a DC-IR analysis is conducted in ANSYS SIwave software, which evaluates the entire design, including coupling effects between traces, packages and boards. The current density and voltage drops are computed in the DC-IR analysis feature of SIwave to ensure that sufficient voltage is supplied to the ICs. Furthermore, the computed results of resistance and current distribution on the board are used to compute localized Joule heating.

In step 2 (model creation), ANSYS SpaceClaim Direct Modeler — which allows the user to move, stretch, add and remove elements with a mouse click —

**Toshiba’s need for accurate analysis of the overall system during the simulation process has grown.**

creates a 3-D model from the PCB's layout data. The model is sent to ANSYS DesignModeler to be simplified and edited before simulation.

For step 3, the ANSYS Workbench platform provides an integrated environment to guide the user through complex multi-physics analyses. Engineers conduct a coupled electromagnetic-thermal simulation that incorporates the data from the SIwave analysis (from step 1) and combines it with data from ANSYS Icepak, which is used for the thermal simulation. Specifically, the power loss information from the electromagnetic simulation is read into Icepak, and the board's plane is set as a heat source in the simulation. Since this is a thermal simulation, the ICs and enclosure are checked to see if they satisfy temperature specifications.

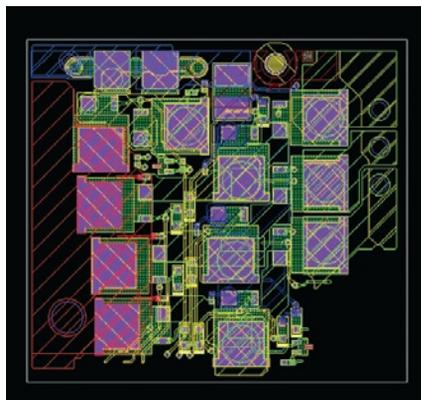
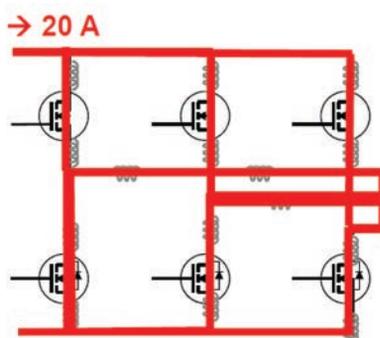
Finally, a coupled thermal-stress simulation is conducted in step 4 using ANSYS Mechanical software. The temperature distribution previously obtained in the thermal simulation is read into ANSYS Mechanical, and the stress results can be used to identify where mechanical failure may occur due to stress caused by heat.

### REAL-WORLD EXAMPLE

Consider the example of simulating a power supply board with a three-phase inverter with 20A of applied current to a single phase. A power supply like this often includes high current flow and high heat generation; therefore, problems of voltage drops, heat and stress can be expected.

The engineer verified the DC-IR drop in the electromagnetic simulation. The required data included the PCB layout data, value of current supplied, and minimum drive voltage for each IC (used to verify acceptable voltage drops). The simulation result showed that the narrow regions on the power plane had high current density, large resistance and, therefore, large voltage drop, suggesting that an ideal power plane would be wide and short. In fact, the simulation revealed that the narrower the plane, the greater the heat generated on the board.

Next, engineers created the model (step 2) and conducted a coupled electromagnetic-thermal simulation (step 3). ANSYS Icepak set the boundary conditions, convection and gravity. Engineers entered the IC's material properties and



▲ Circuit schematic (top) and layout CAD (bottom) for a power supply circuit that involves high current and large heat generation

heat generation values, and imported the Joule heating values from ANSYS SIwave as heat sources for the thermal simulation.

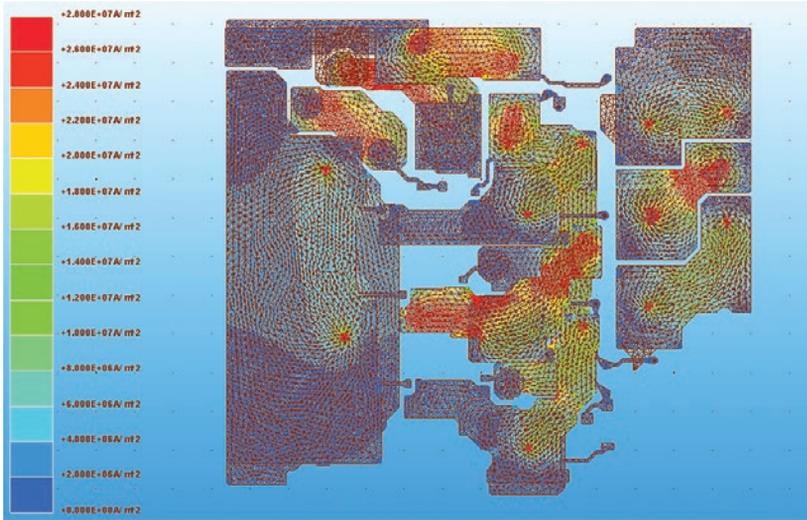
Using this method, engineers could modify the layout model of the PCB and repeat the electromagnetic simulation if they found that the temperature specifications were not achieved in the simulation. Then, the updated PCB data could be directly imported into Icepak, allowing considerable

ease in the study for electromagnetic and thermal optimization.

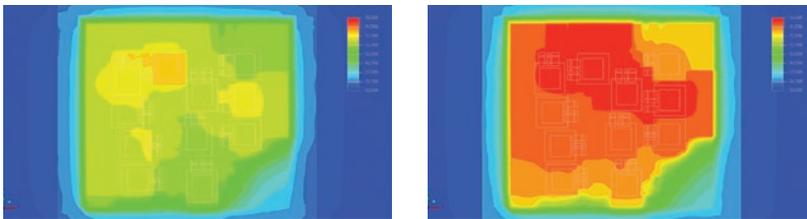
Engineers compared the simulations with and without onboard heat generation (heat transfer from a copper trace to a plane in a PCB when power is supplied to the PCB component) to determine whether onboard heat generation was a concern. When compared with actual measurements, the simulation without onboard heat generation missed the measurements by 10.3 C at the maximum.

## A critical area of product design is improving reliability and product lifetime under real-world conditions.

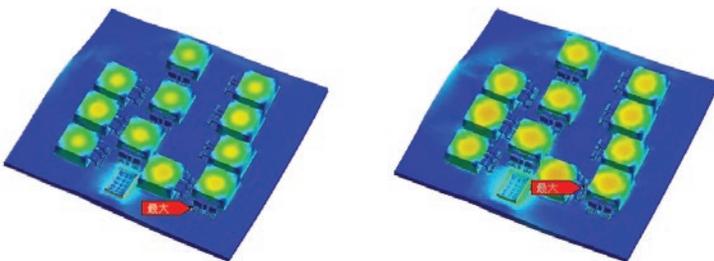
## To accurately predict real-world performance of systems and subsystems, engineers must identify thermal effects and conduct coupled simulations.



▲ Simulation results with SIwave for the circuit indicated that narrow regions on the power plane have high current density and large resistance and, therefore, a large voltage drop.



▲ By including onboard heat generation (right) by coupling with the electromagnetic simulation temperature from SIwave, temperature values as well as their distribution changed in ANSYS Icepak.



▲ The inclusion of temperature distribution from Icepak thermal simulation affected the results of a stress simulation in ANSYS Mechanical. Increased stress and a change in the position of maximum stress are indicated in the simulation that included coupling, on the right.

By including onboard heat generation in the simulation, the error could be reduced to a maximum of 2.3 C. This analysis confirmed that including onboard heat generation improved accuracy, and this result was confirmed by comparison with measurements.

Finally, engineers coupled thermal and stress simulation. ANSYS Workbench read the model from DesignModeler into ANSYS Mechanical and also read the temperature distribution data from Icepak. Engineers input mechanical properties, set constraint conditions for the stress simulation, generated a mesh for the structural simulation, imported thermal simulation results, and conducted a thermal–stress simulation. In this example, the thermal simulation determined that the maximum stress for this design would occur between the IC pins and the board. This made it possible to identify the most problematic region in terms of stress and to optimize the design to address these issues by repeating and iterating electromagnetic and thermal simulation steps within ANSYS Workbench, as needed.

This study confirmed that to accurately predict real-world performance of systems and subsystems, engineers must conduct coupled simulations to identify thermal effects. Using coupled simulation, Toshiba engineers increased the accuracy of temperature predictions and determined stress effects on a power supply board. Employing coupled simulation early in the design process can lead to more reliable products with longer life. ▲

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