Multiphysics Analysis Technology in Cloud-based Integrated Development System

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Multiphysics analysis simultaneously handles multiple physical phenomena, each expressed by different dominant equations, by means of simulation. In recent years, there has been growing demand for the assembly design of electronic devices to provide increased density and capacity, and this trend has given rise to a problem—the generated heat affects their electrical and mechanical properties. In conventional assembly design, simulations are conducted separately for different development aspects before the improvements made to the design are unified. However, this has become inefficient as it is likely to result in having to repeat the design processes. Aiming to address this problem, which has electrical, thermal-fluid, structural, and other aspects, Fujitsu has developed a unique design environment for multiphysics analysis. This analysis environment has been combined with an integrated development platform, which is a design environment built into the cloud. This makes it easier to share data between electrical and structural designers, enabling them to address large-scale model analyses. In this paper, we explain the multiphysics analytical environment in terms of its features and how it provides an integrated solution by combining power integrity, thermal-fluid, and structural analyses. We also present a case study of applying it to the design of small electronic devices.

1. Introduction

Fujitsu has been promoting its Flexible Technical Computing Platform (FTCP) as an integrated development platform using information and communications technology (ICT) since 2007 and has come to integrate its electrical-design and structural-design development platforms on FTCP.[1] FTCP is helping to make development work more efficient by providing circuit, assembly, and structural CAD tools and associated design-rule-check functions and libraries and by enabling information sharing between electrical and structural designers. The conventional design technique is to identify the most promising suggestions made in each development field for design improvements and to compare and adjust them to achieve a final proposal for design improvement. This technique, however, makes it easy for tradeoffs to occur between the various fields. In contrast, information sharing between development fields as supported by FTCP enables an inter-field approach to examining and prioritizing such tradeoffs so that an optimal level of performance and quality can be achieved. Various types of simulation software for electrical, thermal-fluid, and structural analysis are also included in FTCP to enable more accurate identification of defect locations in equipment designs.

Nevertheless, a technique that executes simulations on a field-by-field basis and combines the results of those individual simulations as design improvements can still result in reworking that hinders gains in efficiency. In response to this problem, Fujitsu has undertaken the practical use of multiphysics analysis to enable efficient problem solving by handling the problems from each field in a composite manner. In contrast to conventional simulation techniques, which rely heavily on commercially available software, the goal here is not only to link the data of CAD and in-house tools but also to support the solving of problems that are too large to be handled with conventional techniques.

In addition, Fujitsu is incorporating a multiphysics analysis environment on FTCP and providing it in its Engineering Cloud to make the use of multiphysics analysis more convenient for designers. The Engineering

Cloud provides an environment that facilitates the operation of 3D CAD and other sophisticated tools on a cloud platform through Remote Virtual Environment Computing (RVEC, pron. "rĕ-vĕc′"), Fujitsu's high-speed image-compression and data-transfer technology. When applied to a virtual desktop environment, RVEC can reduce the amount of data transferred in the handling of video and high-definition images to about one-tenth that of conventional techniques, thereby improving the operational responsiveness of the user's client terminal.[2)]

In a conventional client/server environment, a problem in large-scale analysis is the time needed to transfer data between the file server storing analysis results and the designer's terminal. Fujitsu's Engineering Cloud environment greatly reduces the time it takes to transfer large-scale data because a high-performance engineering workstation is installed close to the file server storing the analysis results, and visualization processing of those results is executed on that workstation, which is connected to the designer's terminal. At Fujitsu, providing multiphysics analysis technology on FTCP in a cloud environment promotes information sharing between electrical and structural designers and supports the solving of large-scale problems.

This paper describes the features of the multiphysics analysis technology that has been added to the cloud-based FTCP integrated development environment and presents a case study of its application.

2. Flow of coupled calculations

Multiphysics analysis solves the governing equations for multiple physical phenomena in an integrated manner through simulation. Fujitsu has constructed a multiphysics analysis environment for coupling power-supply analysis, thermal-fluid analysis, and structural analysis and finding integrated solutions. The following describes the flow of the power-supply, thermal-fluid, and structural coupled calculations (**Figure 1**).

The first task is to calculate the current distribution in printed circuit board (PCB) wiring by inputting materials and wiring information for the PCB into the power-supply analysis program from the assembly CAD tool. Power-supply analysis makes use of the FTCP SignalAdviser-PI tool incorporated in FUJITSU Manufacturing Industry Solution FTCP SignalAdviser, an anti-electrical-noise design system. FTCP SignalAdviser-PI can quickly simulate the power-supply noise caused by fluctuations in consumed current associated with LSI operation on the PCB.

The PCB simulation model uses the partial element equivalent circuit (PEEC) method (**Figure 2**), which replaces the power and ground pattern of the PCB with an equivalent circuit consisting of resistance (R), inductance (L), and capacitance (C) elements represented in the form of an RLC mesh model. The PCB simulation model consists of this RLC mesh model, voltage regulation components, capacitors, and LSI equivalent circuits as noise sources. It is analyzed by

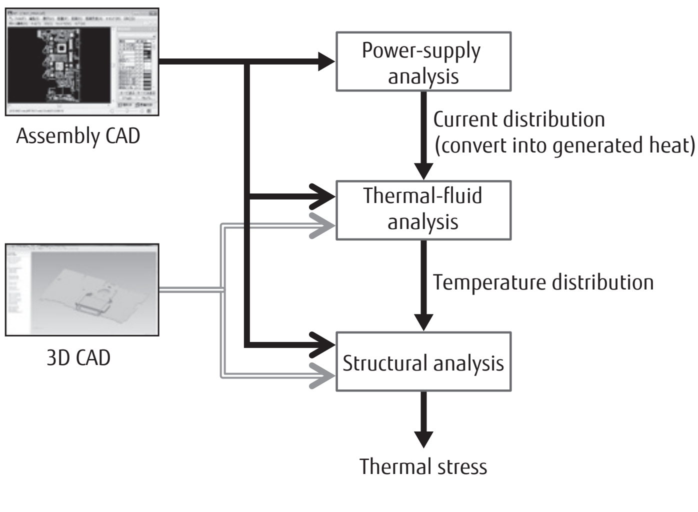

Figure 1
Flow of power supply, thermal-fluid, and structural coupled calculations.

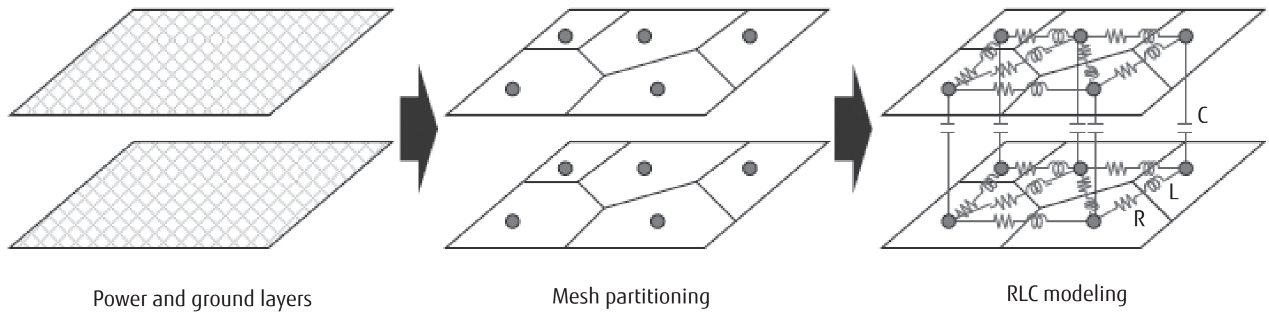

Figure 2
PEEC method.

using a circuit simulator to calculate power-supply impedance, voltage drop, and current distribution.

In simulations using this technique, the approximations used for RLC mesh modeling of the various parts making up the power-and-ground pattern of the PCB affect analysis accuracy. Making the mesh in the model finer improves accuracy but increases analysis time. Up to now, using a combination of techniques for reducing the number of mesh elements and improving the circuit simulators has been successful in achieving environments that can handle the analysis of large-scale PCBs (more than 20 layers) in about one hour.[3)]

The next task is to convert the current distribution obtained by power-supply analysis into generated heat for use in thermal-fluid analysis, which is performed using Fujitsu's FS-Solver Thermal Flow software developed using OpenFOAM open source software code. OpenFOAM, a registered trademark of OpenCFD Ltd. of the ESI Group (France), is a collection of physical-field computational applications provided in the form of a GNU General Public License (GPL).

Simply dividing the CAD model of an electronic device having a large number of components into a mesh increases the scale of the calculation model. To deal with this problem, CAD shape-correction preprocessing is needed to simplify the shapes or recreate the model using simpler shapes for the sake of analysis modeling. However, expert knowledge or experience related to thermal-fluid analysis is needed to correct CAD shapes without negatively affecting the calculation results. Such work, moreover, requires considerable time, which has been a major obstacle to the use of thermal-fluid simulation by general designers.

In contrast, FS-Solver Thermal Flow enables relatively quick calculation of a large-scale model created by direct mesh modeling of the CAD model due to the parallel-computing scalability of OpenFOAM and the enhancements made by Fujitsu to the calculation algorithm. This eliminates the need for CAD shape-correction work and enables even general designers with no expert knowledge to apply thermal-fluid simulation to product development.

The final task is to calculate the thermal stress on the wiring pattern through structural calculations using the temperature distribution of the PCB obtained by the thermal-fluid analysis. These calculations are done using Fujitsu-enhanced FS-Solver Structural software based on FrontISTR, a large-scale structural analysis program using the finite element method, which was developed under the leadership of Professor Hiroshi Okuda of the Graduate School of Frontier Sciences, the University of Tokyo.

The FS-Solver Structural software includes a function for automatically detecting portions of a PCB in which structures defined by the analysis model may come into contact with each other. This function enables contact calculations to be made without missing any contact-condition settings even in the case of structural models with complex shapes and many components. In addition, the use of a proprietary contact-calculation technique has improved the convergence of contact calculations due to the use of an iterative method difficult to implement in the past. A reduction in the amount of communication between CPU cores during multi-node parallel calculations has also improved parallel scalability during large-scale contact calculations.

In the above way, FS-Solver features excellent scalability in parallel calculations and the capability of calculating both micro and macro phenomena in a large-scale model (**Figure 3**).

3. Analysis-data coupling technology

Achieving multiphysics analysis as described above requires that the calculation results obtained by the FTCP SignalAdviser-PI, FS-Solver Thermal Flow, and FS-Solver Structural tools be passed to downstream software. Power-supply analysis, thermal-fluid analysis, and structural analysis all represent objects and space in the form of a mesh model as a basis for performing simulations. However, a mesh structure applicable to each type of analysis must be used to ensure sufficient calculation accuracy, and, as a result, each software program outputs data based on a different mesh structure.

Typical examples of mesh structures used in power-supply analysis, thermal-fluid analysis, and structural analysis are shown in **Figure 4**, which illustrates a Voronoi grid for power-supply analysis, a structured grid (hexahedron) for thermal-fluid analysis, and an unstructured grid (tetrahedron) for structural analysis. The differences in these mesh structures must be taken into account when passing data. We use a method based on linear interpolation to map data between analyses using different mesh structures. This method derives the center coordinates of each mesh element and performs data mapping using the offset between those coordinates.

4. Case study: Testing for risk of disconnections in PCB wiring

The downsizing and low-voltage operation of LSI devices has been progressing in recent years, resulting in significant drops in power consumption. At the same time, a drop in power-supply voltage means an increase in supply current; therefore, very small changes in resistance can cause voltage drops that can lead to operation faults. In addition, LSI sections with high current density increase the risk not only of voltage drops but of other problems as well such as disconnections in PCB wiring due to thermal expansion caused by heat generation and burnouts caused by increasing resistance. Fujitsu aims for low-voltage operation in its smartphones and supercomputers to improve execution performance per unit of electric power. Consequently, clarification of potential risk in low-voltage PCBs in the initial development stage to ensure product quality has become a priority in the development process.

In relation to the above, the following presents a case study of applying coupled analysis to the design of small electronic devices. In this regard, mobile devices such as smartphones have been experiencing a significant increase in the power consumed by their electronic components in parallel with a rapid rise in device performance. As a result, the current passing through PCB

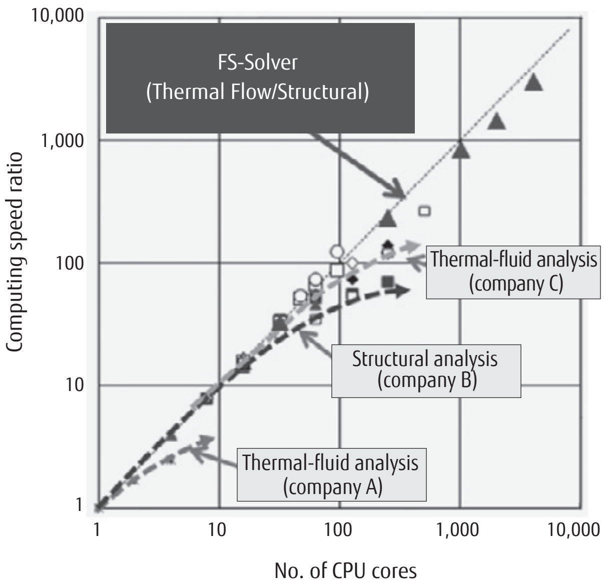

Figure 3
Comparison of Computing scalabilities.

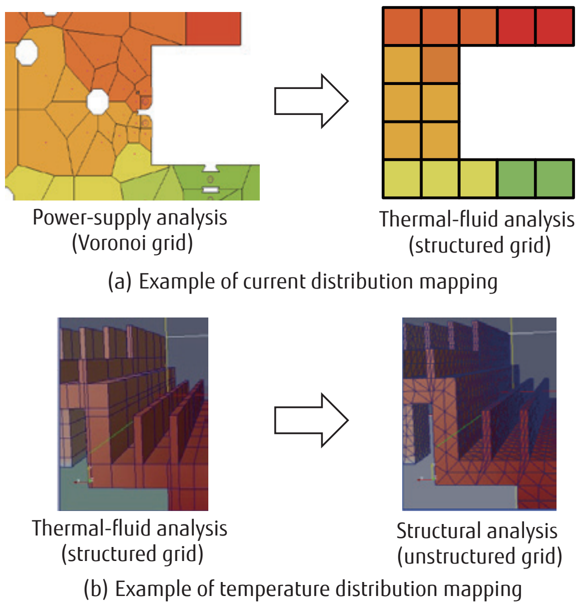

Figure 4
Examples of data coupling in coupled analysis.

wiring has been increasing to the point that the heat generated by that current can no longer be ignored. When current passes through wiring, it may concentrate and become a significant heat source depending on the shape of that wiring. It is therefore necessary to accurately predict the thermal stress caused by a rise in temperature on a PCB, and, to this end, the use of an accurate current density distribution is essential. We therefore applied the power-supply, thermal-fluid, and structural coupled analysis technologies described above to the PCB of a small electronic device and derived the thermal stress from the temperature rises caused by current passing through wiring.

The target of our simulation was a 12-layer substrate for a mobile electronic device with dimensions of approximately 60 × 60 mm. Additionally, given concerns about increases in thermal expansion and stress due to heat generation in wiring, we analyzed two cases in terms of the width of the PCB wiring for comparison purposes: one with narrow wiring and the other with wide wiring.

First, we calculated the density of current in the PCB wiring using FTCP SignalAdviser-PI. We applied a current source to pads on the PCB where an electronic component is to be connected and input current. The results are shown in **Figure 5 (a)**. Comparing the narrow-wiring case with the wide-wiring case, we found that the amount of wiring with dark-colored current densities in the latter case was about half that in the former case. Next, to clarify how such a difference in current density affects temperature and stress, we performed coupled analysis. We began by calculating the amount of heat generated by the current density distributions obtained in the power-supply analysis and performing a thermal-fluid analysis. Simulation conditions are summarized below.

- Natural convection and radiation were considered.
- Number of mesh elements: approx. 20 million
- Computer: FUJITSU Server PRIMERGY RX200 S7
- CPU: Intel Xeon Processor E5-2660 (2.20 GHz)
- Simulation time: approx. 5 hours (48-core parallel processing)

The temperature distributions for wiring in which the current became concentrated are shown in **Figure 5 (b)**. The color is darker at locations where the current concentrated, signifying higher temperatures. It was lighter at other locations, where the temperature rise was small. The temperature in the case of wide wiring was about 30°C less than that in the case of narrow wiring.

Wiring can become deformed through thermal expansion at locations that are considerably higher in temperature than the peripheral area, and the resulting thermal stress can increase the risk of a disconnection. For this reason, we next performed a structural analysis (actually a thermal stress analysis) using the temperature distributions obtained using the above method. The stress distributions for the same wiring are shown in **Figure 5 (c)**. Stress increases at locations where temperature rises, and it can be seen that stress concentrated in the bent section of the wiring in the case of narrow wiring, which raises concerns about a disconnection occurring at that location. In contrast, a concentration of stress is not noticeable at that location in the case of wide wiring. We have therefore shown through the use of coupled analysis that increasing the width of wiring on a PCB can reduce the concentration of stress.

The above case study showed how current density distributions, temperature distributions, and stress distributions in a small mobile electronic device can be derived using coupled analysis combining electrical, thermal-fluid, and structural factors. These results point to the possibility of enhancing the reliability of PCBs by making improvements in their wiring design.

5. Future activities

Fujitsu's proprietary multiphysics analysis environment currently supports steady-state simulations as a first step. It cannot, as yet, be used to evaluate how temporal changes in electric current in a module with large fluctuations in load—as in the supply of power to a multi-core CPU—affect thermal stress in structures. We plan to add non-steady-state calculation functions in the future to support such an application.

Additionally, considering that data sharing between different fields of analysis is achieved by file linking, we can expect bottlenecks to occur in non-steady-state analysis in which the calculation results of each field have a mutual affect on each other. With these issues in mind, our current objectives are to achieve data linking through memory sharing and to develop non-steady-state multiphysics analysis technology that can support large-scale models, leveraging

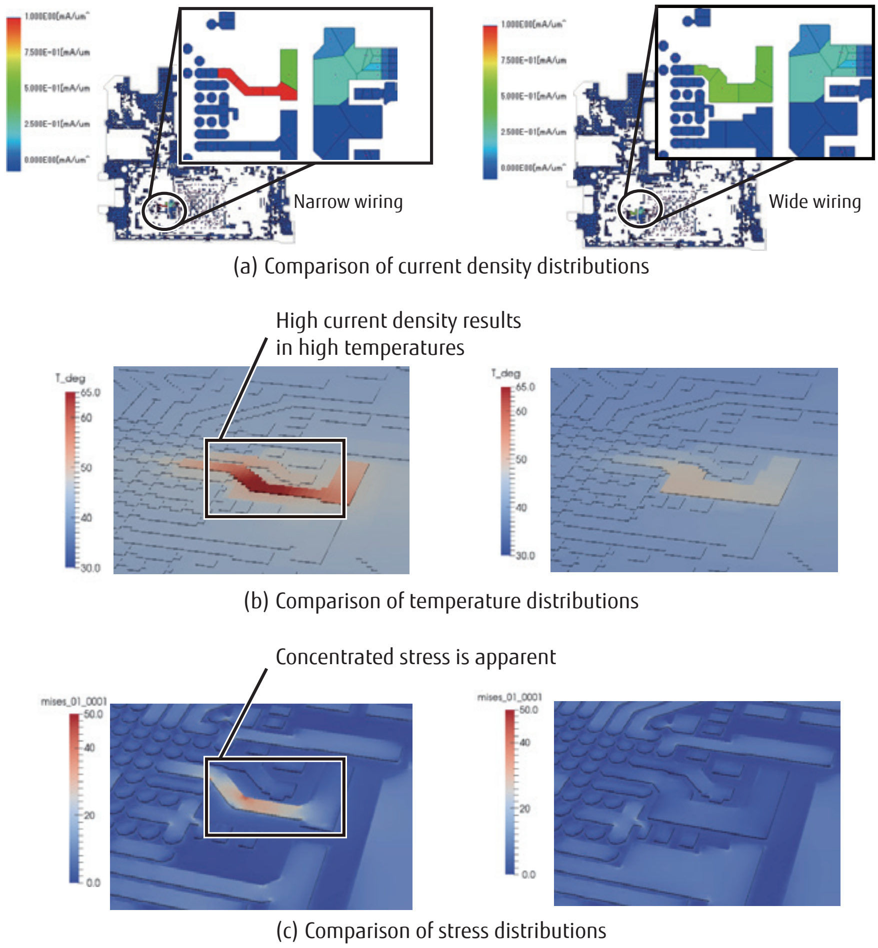

Figure 5
Example of calculations for PCB used in mobile electronic devices.

the parallel-calculations scalability of FS-Solver.

6. Conclusion

We outlined Fujitsu's Flexible Technical Computing Platform (FTCP) provided in Fujitsu's engineering cloud and described the multiphysics analysis environment added to this platform. We also presented a case study of applying this environment to multilayer PCBs for small electronic devices. The FTCP fortifies the link between electrical designers and structural designers. It also supports efficient handling of the tradeoffs generated among different development fields and facilitates product development with no reworking through multiphysics analysis technology. A current topic in multiphysics analysis is enabling its application to detailed evaluation of temporal changes of a phenomenon through a functional extension, from existing steady-state calculations to non-steady-state calculations.

Going forward, Fujitsu aims to make development work more efficient and improve product quality by pursuing further advances in multiphysics analysis technology on FTCP.

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