Application Examples of Electromagnetic Field Analysis at Fujitsu

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As the operating frequency of printed circuit boards (PCBs), multichip modules (MCMs), and systems-in-packages (SiPs) used in digital devices such as high-performance, high-end servers has been increased and as the operating voltage of large-scale integration (LSI) chips has been lowered, it has become difficult to implement countermeasures against electromagnetic interference (EMI)—which is attributed to various noise sources such as signal-transmission noise, ground-bounce noise in power supplies, and simultaneous switching noise—and degradation of antenna receiver sensitivity. Fujitsu Group has developed a large-scale electromagnetic field analysis system and incorporated it in the equipment-design process so that countermeasures against such noise sources can be implemented in the design stage. Utilizing this system has made it possible to eliminate instances in which designs have to be redone because of noise problems for various Fujitsu products, ranging from the K computer to cell phones. This paper describes the features of the developed analysis system and gives examples of its application to equipment design.

1. Introduction

The operating frequency of printed circuit boards (PCBs), multichip modules (MCMs), systems-in-packages (SiPs), and so on used in digital devices such as high-performance, high-end servers is continuing to be steadily increased. Moreover, to improve performance and functionality, cutting-edge process-miniaturization technology is being incorporated into the LSIs mounted in these devices in order to increase the degree of integration. However, this has led to increased current consumption of the LSIs. To suppress the increase in power consumption due to these increases in operating frequency and current consumption, efforts aimed at voltage reduction and LSI miniaturization have been continuing. As a result of these trends, problems such as ground-bounce noise in power supplies, simultaneous switching noise, and return current, which arise in association with time variation of consumed current during LSI operation, are coming to the surface. Consequently, it is becoming extremely difficult to design devices in such a manner that the electromagnetic interference (EMI) (i.e., the source of the above-described noises) that they generate conforms to electromagnetic compatibility (EMC) specifications.[1] Moreover, increased packaging density of devices as well as miniaturization and voltage reduction of LSIs are making it more difficult to make devices resistant to electrostatic discharge (ESD), which takes the form of degraded antenna receiver sensitivity in the case of mobile devices like cell phones. Furthermore, complicated noise problems that arise as a result of the combining of conducted and spatially propagated noises from the various abovementioned noise sources are becoming more prevalent. These combined noise problems are hereinafter referred to as “compound noise.”

In particular, if definite measures are not taken against problems such as EMI, ESD, and degraded antenna receiver sensitivity during the design stage, failures will occur and only be detected during prototype testing, so extensive reworking of designs will be needed. Such reworking often increases costs due to multiple redesigns of components and implementation of excessive countermeasures, in addition to extending development times. To deal with these noise problems, countermeasures based on electromagnetic field analysis using either element models focusing on device interiors or simplified housing models have been investigated. Owing to a lack of precision, however, definite measures have not been sufficiently implemented during the design stage. This situation has led to increased equipment costs due to the need for design rework during the prototype testing stage and the implementation of excessive countermeasures.

Fujitsu is aiming to improve the precision of electromagnetic field analysis by establishing and applying a large-scale electromagnetic field analysis system that can execute high-precision analysis using fine models of devices.[2),3)] Since this system will enable analysis of a complete device with high precision and a short turnaround time (TAT), it will enable noise countermeasures designed using electromagnetic field analysis to be incorporated into the device design process.

This paper presents case studies of the efforts of Fujitsu to craft countermeasures against compound noise (represented by EMI, ESD, and degraded antenna receiver sensitivity) during the early stage of design.

2. Configuration of large-scale electromagnetic field analysis system

Since the PCB connectors in a device, the cabling and packaging, and the environment itself play roles in EMI, ESD, and degraded antenna receiver sensitivity, electromagnetic field analysis of compound-noise problems with high precision requires the creation of a detailed device model and its environment (**Figure 1**).

At Fujitsu, such electromagnetic field analysis of a device is done using Fujitsu's finite difference time domain (FDTD) method (which offers outstanding analysis scalability). With FDTD, the analysis space is conventionally divided into a grid mesh with uniform cell size. However, high-precision analysis requires that a fine mesh be used, resulting in an enormous number of cells for a detailed device model. The required memory space and extremely long analysis time for such a mesh makes analysis practically impossible. More specifically, the widths of fine wiring patterns on PCBs are of the order of 100 µm; accordingly, to analyze such patterns with high precision, the cell size (i.e., mesh size) must be set to less than several tens of micrometers. This means that, for devices like those produced by the Fujitsu Group, the number of cells is of the order of 10^{13} (i.e., ten trillion) (**Figure 2**). At such a mesh scale, analysis is impossible. To make analysis possible, it is necessary to greatly reduce the mesh scale while ensuring adequate analysis precision. To meet this requirement, several schemes for dividing the analysis space into a grid mesh have been devised and implemented.

While the analysis space for components that require a fine mesh wiring pattern is

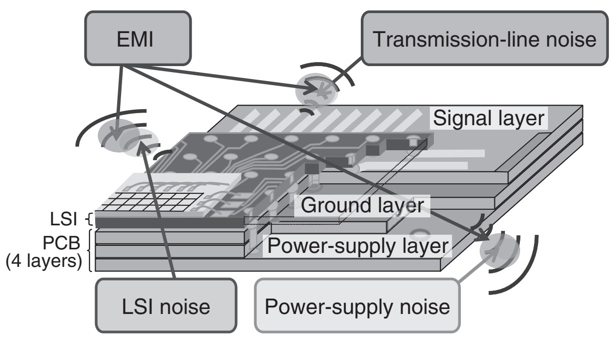

Figure 1
Device model used for analyzing compound-noise problems.

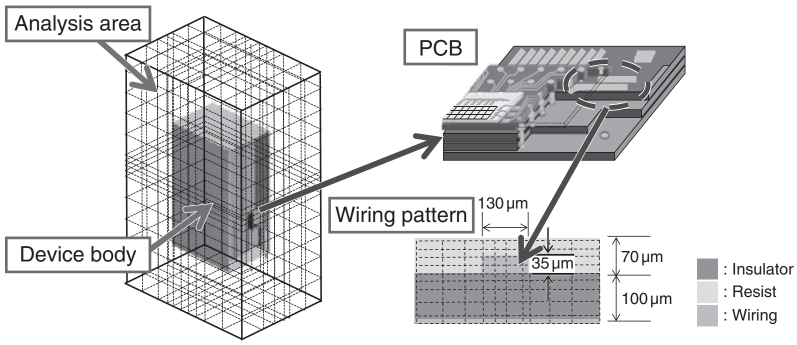

Figure 2
Device analysis using fine mesh with reduced scale.

divided into a fine mesh, the space for the device package and its environment is divided into a coarser mesh. However, the mesh size is still sufficiently smaller than the wavelength of the electromagnetic waves determined by the operating frequency of the device. At the same time, enlarging the mesh size while preserving the device configuration during modeling—in other words, simplifying the device configuration—has a limit. Consequently, the mesh size is optimized by achieving a good balance between wavelength and configuration preservation. By incorporating the above-described schemes into Fujitsu's large-scale electromagnetic field analysis system and automating them, it became possible to significantly reduce mesh scale to the order of 10^9 (i.e., one billion).

As a result of incorporating large-scale electromagnetic field analysis in the design process, which makes it possible to design noise countermeasures in the design stage, the maximum allowable TAT for device analysis is a few days. However, even if the mesh scale is reduced to the order of 10^9 through the abovementioned schemes, the analysis time for analysis executed on a single PC will be several months.

In response to those circumstances, Fujitsu has constructed a large-scale PC cluster environment composed of several hundred PCs and incorporating an electromagnetic field solver in an Engineering Cloud environment to enable device analysis with a short TAT. However, when data from a large-scale electromagnetic field analysis is placed in an Engineering Cloud environment and when video images of electromagnetic field maps are presented on the client side via a network, the volume of data is large (~50 GB) when conventional technology is used. This greatly reduces the display speed (to ~0.3 frames per second). To solve this problem, Fujitsu has developed a unique high-speed technology and used it to speed up the display rate one hundred times (i.e., to 30 frames per second) compared with that possible with conventional technologies.[4)]

The configuration of the constructed large-scale electromagnetic field analysis system incorporating the various new technologies described above is shown in **Figure 3**. This system links a PCB-layout/interconnection CAD system and a 3D-CAD system (which form an integrated design and development environment called a "Flexible Technical Computing Platform" [FTCP]), captures PCB design data and structural data, automatically generates electromagnetic field analysis models, and transfers these models to a 3D electromagnetic field solver. The 3D electromagnetic field solver can execute large-scale calculations with a short TAT by utilizing the parallel-computing function of the PC cluster. Moreover, electromagnetic field distribution data from the analysis results placed in the PC cluster environment can be

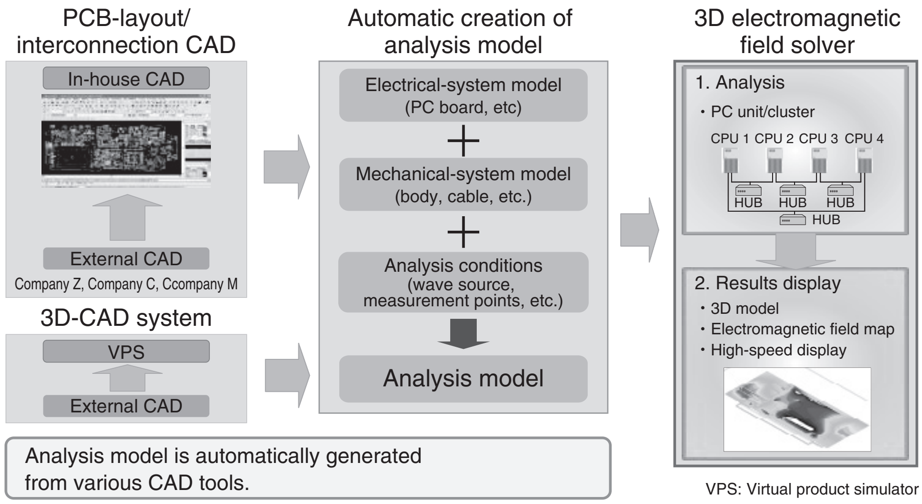

Figure 3
Configuration of large-scale electromagnetic field analysis system.

rapidly presented via a network as video images on the client side by means of a high-speed display function.

3. Application examples of large-scale electromagnetic field analysis

3.1 Analysis of EMI affecting the K computer[note)]

An example application of electromagnetic field analysis to EMI is its use to develop countermeasures against EMI affecting a supercomputer, namely, the K computer being developed by RIKEN and Fujitsu under the guidance of the Ministry of Education, Culture, Sports, Science and Technology.

Developed with higher clock frequencies for the CPU, internal bus, interface bus between I/O devices, and other components, this supercomputer has reached operation frequencies in the ultra-gigahertz band. To be able to operate in this band, however, it must have an abundance of external-component interfaces and cooling apertures, so the problem of EMI in the ultra-gigahertz band is becoming more and more apparent.

Electromagnetic field analysis for conventional server equipment is generally performed on both boards and housings, and designs to counter electromagnetic waves are devised in the design stage. However, implementing electromagnetic wave countermeasures during the design stage for equipment operating in the ultra-gigahertz band necessitates electromagnetic field analysis of the whole apparatus—from the PCBs to the housing. We have made it possible to analyze the whole apparatus by setting up a calculation environment suitable for such large-scale electromagnetic field analysis and by improving the interface function, which makes it possible to simplify the design of models obtained from the PCB-design and mechanical-design CAD systems that are used for solving Maxwell's equations. Shortening the analysis TAT to within a few days made it possible to incorporate this electromagnetic field analysis into the device-design flow and thereby make it available in practice.

Another example is the use of electromagnetic field analysis to identify the mechanism by which the ultra-gigahertz-band

note) "K computer" is the English name that RIKEN has been using for this supercomputer since July 2010. "K" comes from the Japanese word "Kei," which means ten peta or 10 to the 16th power.

electromagnetic waves emitted by the system clock leak from the equipment and to develop a countermeasure that effectively reduces the resulting EMI. As shown in **Figure 4**, the countermeasure is the placement of a gasket in the gap between the metal sheets of the housing to prevent electromagnetic radiation from escaping from the CPU to the exterior of the housing. As shown in **Figure 5**, introducing the gasket reduced EMI by more than 5 dB in the ultra-gigahertz band, thereby ensuring that the margin specified in the VCCI CLASS-A standards is attained.

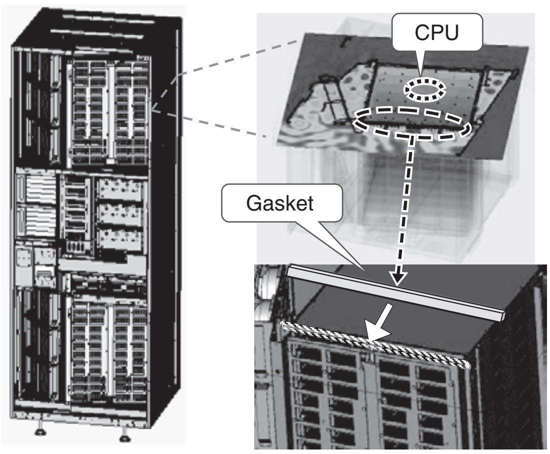

Figure 4
Placement of gasket in gap between metal sheets of housing as countermeasure against EMI.

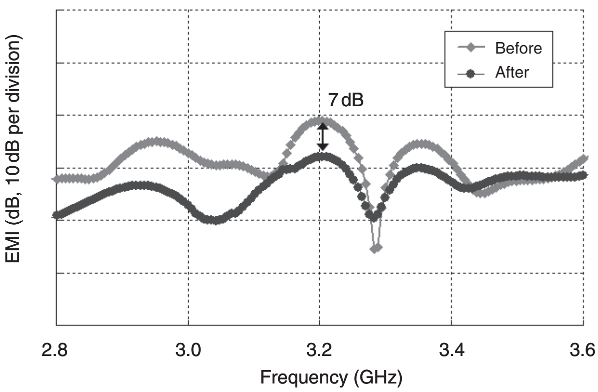

Figure 5
Effect of countermeasure (gasket) on EMI.

3.2 Analysis of ESD affecting notebook PCs

An example application of electromagnetic field analysis to ESD is its use to develop countermeasures against ESD in notebook PCs. Rough CAD data obtained during the upstream design stage is used to construct models of the metal parts of the housing, connectors, and power-supply cables. Only the ground layer of the PCBs is modeled, and electrical discharge (whereby static electricity directly contacts connectors) is simulated. The analysis scale for such a simulation is a mesh size of 2.3×10^8. Although this is a scale rarely seen for tools used by other companies, utilizing a large-scale analysis environment made it possible to execute analysis on 80 CPUs and complete it in about nine hours.

Two cases were simulated in this example application (**Figure 6**): a notebook PC circuit board was either grounded or ungrounded to a heat sink (for CPU cooling). It was grounded in three places (three fixing screws). The effect of grounding on ESD noise was determined by visualizing the electromagnetic field distribution in each case. The distributions before implementing the countermeasure (ungrounded state) and after implementing the countermeasure (grounded state) are shown in **Figures 7 (a)** and **(b)**, respectively. It is clear from the figures that the electric field around the CPU (marked by the ellipse in the figures) was

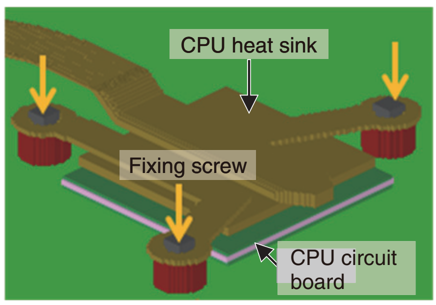

Figure 6
Grounding of notebook PC circuit board to CPU heat sink through fixing screws.

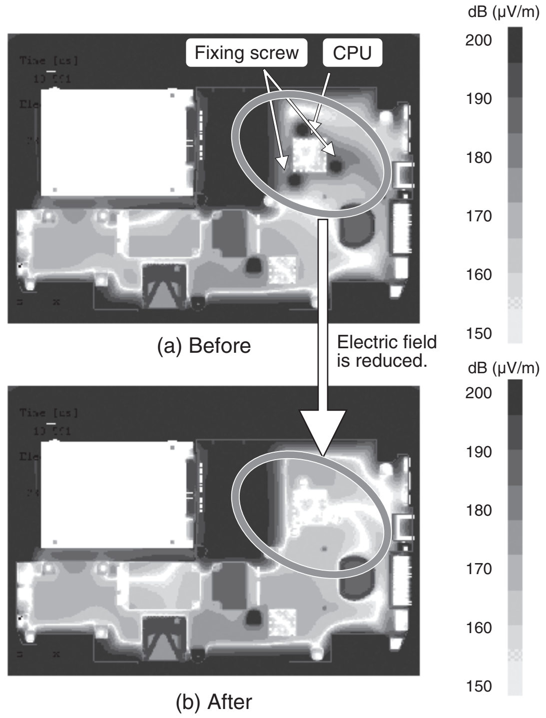

Figure 7
Effect of grounding notebook PC circuit board to CPU heat sink.

reduced about 10 to 15 dB by the grounding. This demonstrates that grounding the circuit board to the CPU heat sink is an effective countermeasure for reducing ESD.

3.3 Analysis of radiation efficiency of notebook PC antennas

Another example application of electromagnetic field analysis is its use to establish a technique for analyzing antenna radiation efficiency as a basis for evaluating antennas in notebook PCs. The antennas and liquid crystal display (LCD) panel (including the metal hinge, i.e., the antenna ground) of a notebook PC and their periphery were modeled as shown in **Figure 8**. The antennas were the main and sub-antennas for Universal Mobile Telecommunications System (UMTS) connection and four antennas on the edge of the LCD panel for wireless LAN connection. There were 77 million cells in the mesh used in the analysis,

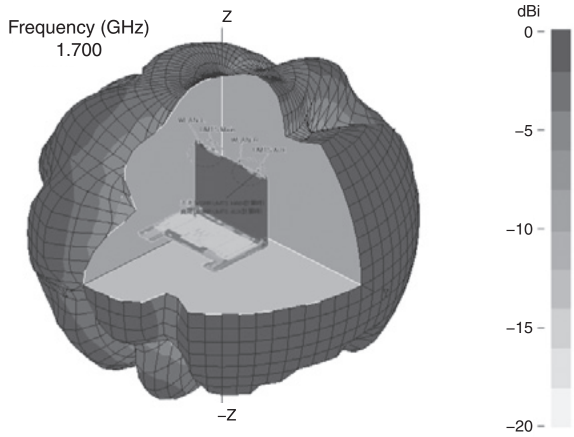

Figure 8
Model of antennas, LCD panel, and their periphery in notebook PC.

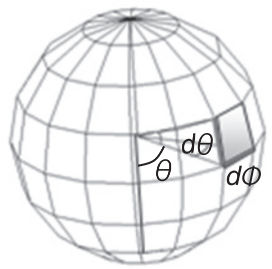

Figure 9
Combined electric-field emission pattern for antennas in notebook PC.

and the analysis time was 4.5 hours on 40 CPUs.

Since antenna efficiency is the ratio of the antenna's input power to its output power, it is necessary to determine the field emission pattern for each antenna and to sum up the magnetic fields. The combined field emission pattern for the antennas is shown in **Figure 9**. This surface area gives the total electric field E_{total}. Antenna efficiency is given by

$$\eta = \frac{1}{4\pi}\int E_{total}\sin\theta d\theta d\phi.$$

As shown in **Figure 10**, the measured and analyzed antenna efficiencies agree well. Even in the high-frequency band (around 2 GHz), they agree well despite the high-frequency loss. Incorporating this large-scale electromagnetic field analysis into the design process would make

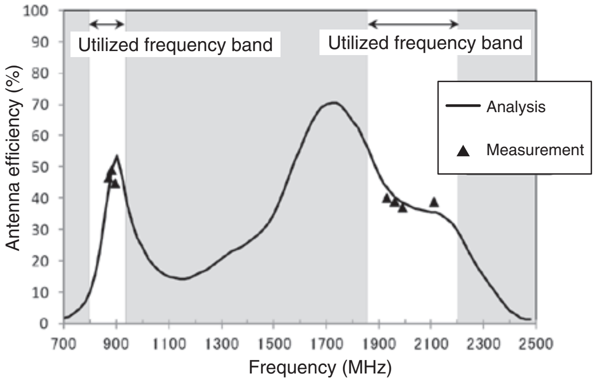

Figure 10
Measured and analyzed antenna efficiencies.

antenna design more efficient and reduce the number of prototype antennas needed.

4. Conclusion

Fujitsu's efforts to improve the precision of electromagnetic field analysis include establishing and applying a large-scale electromagnetic field analysis system that can execute high-precision analysis using fine device models. To enable analysis at the device level, methods for generating and simplifying analysis models were developed, and a large-scale parallel electromagnetic field analysis environment based on a PC cluster was constructed. These efforts have made it possible to analyze the electromagnetic field of a device within a few days, incorporate electromagnetic field analysis into the device-design process (a hitherto difficult task), and devise countermeasures against noise such as EMI and ESD during the design stage. As a result, it is possible to reduce design reworking necessitated by failure in the prototype testing stage and to reduce the cost of production and development as well as the number of countermeasure components. Future work includes finding ways to reduce costs even more and making improvements in the technology, such as increasing the operating frequency, reducing the operating voltage, and increasing the packaging density. Moreover, we will continue our efforts towards further shortening analysis TAT and improving analysis accuracy.

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