Integrated Design Environment to Support Innovation in Manufacturing

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To quickly satisfy the requirements of production, assembly, testing, and maintenance in manufacturing and the market requirements for higher performance, miniaturization, and cost reduction, it is necessary to have an innovative design methodology that facilitates optimization of the entire development process and enables it to proceed without repetition. Fujitsu has developed an integrated design environment for the entire Fujitsu Group to promote innovation in product development and manufacturing. This environment incorporates EMAGINE, an integrated CAD environment for electrical design, which meets the above requirements by providing simulation tools for all design processes and facilitating DFM/DFT and the coordination of PCB design with structural design. This paper outlines EMAGINE, focusing on a system that supports innovation in manufacturing, and then describes its noise simulation and structural design environments.

1. Introduction

In response to the rapid shift towards higher performance and functionality; greater compactness, lightness, and robustness; and lower costs now being seen in electronic products, it is necessary to further reduce the time taken for design. In addition, there are strong demands for environment-friendly designs and production methods, all of which make product development extremely difficult.

Within the Fujitsu Group, in addition to creating an integrated design environment that enables the optimization of everything from product design to manufacturing in order to quickly meet these widely ranging design requirements, we have also been introducing design methods that reduce design remakes in subsequent stages.

In this paper, focusing on support for innovative manufacturing, we outline EMAGINE, which is Fujitsu's integrated computer-aided design (CAD) environment for electrical design, and then look at a noise simulation environment. Lastly, we describe our efforts towards creating a structural design environment.

2. Outline of integrated design environment

The product design process goes through conceptual design, detailed design, trial production and evaluation, and then mass-production. In product development, to reduce the need to remake designs after the test production stage, all design processes are verified through simulations of signal and power source noise, drop shocks, heat radiation, and other factors. Further, to improve workability and facilitate testing at the mass-production stage, a design rule check (DRC) for Design For Manufacturing/Design For Test (DFM/DFT) must be performed to make thorough design improvements. Within the Fujitsu Group, we have created an environment under which such verification can be coordinated within a single CAD framework that enables trade-off designs to be made in a short period of time (**Figure 1**).

3. Integrated CAD environment: EMAGINE

Figure 2 shows the EMAGINE design environment. EMAGINE is widely used for the design of printed circuit boards (PCBs) for Fujitsu Group server equipment, mobile terminals, and transmission devices and supports all design processes from conceptual design to the preparation of manufacturing data and assembly drawings. It also forms an overall framework for design through an organic linkage with structural design.

The backend consists of management tools of libraries and design assets, for example, the integrated components library FCOMAS and the design assets management Internet data center (IDC), as well as IT environments that allow sharing of costly market tools such as an internal CAD application service provider (CAD-ASP) and CAD-Grid.[1] By interconnecting the PCs used for design work, the front-end of design realizes reductions in the total cost of ownership (TCO) as well as simultaneous coexistence with office automation (OA) jobs.

In the Fujitsu Group, a total of around 10 000 licenses are in use, not just by PCB designers but also by analytical engineers and factory testing staff.

3.1 Application of CAD tools from the conceptual design stage

At the conceptual design stage, the detailed design is steadily worked out while evaluating and analyzing aspects such as wiring accommodation, signal integrity, costs, thermal management, and

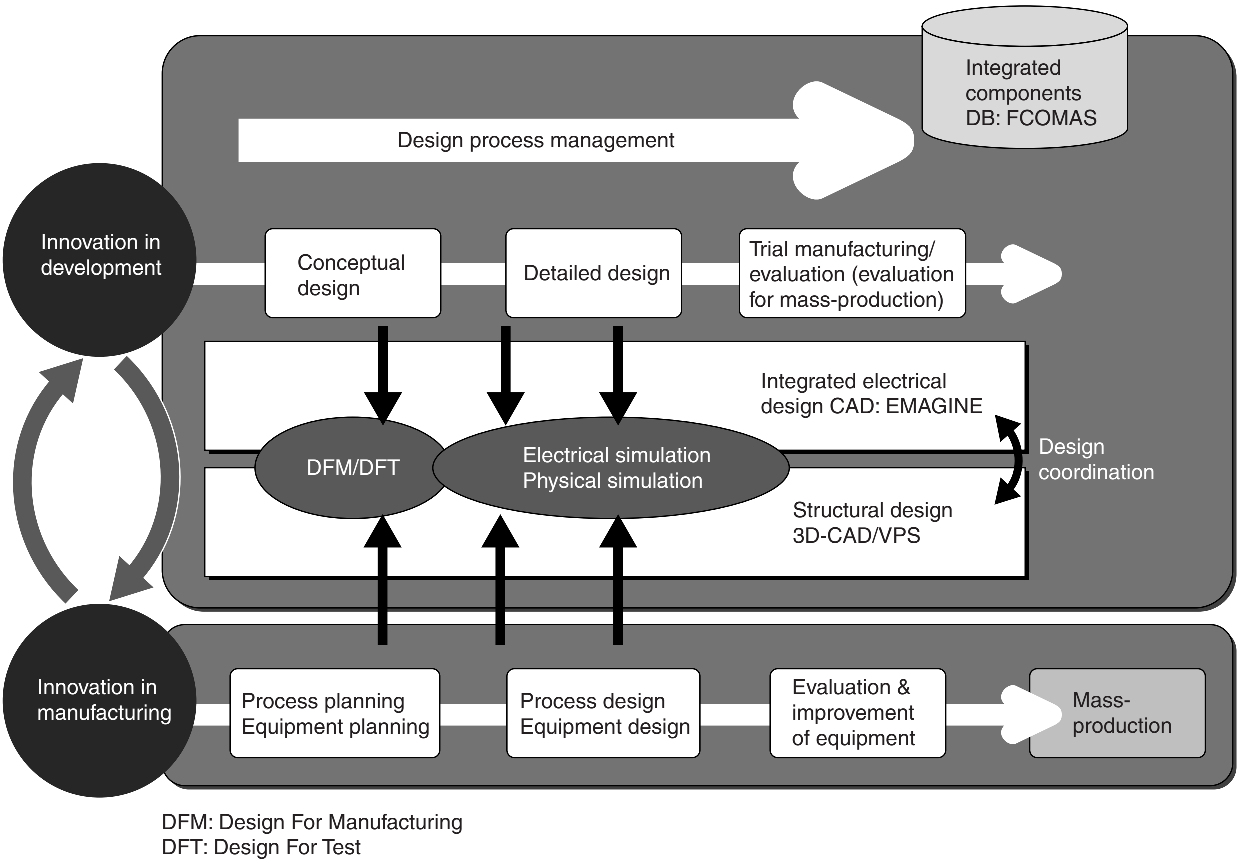


Figure 1
Fujitsu Group's integrated design environment.

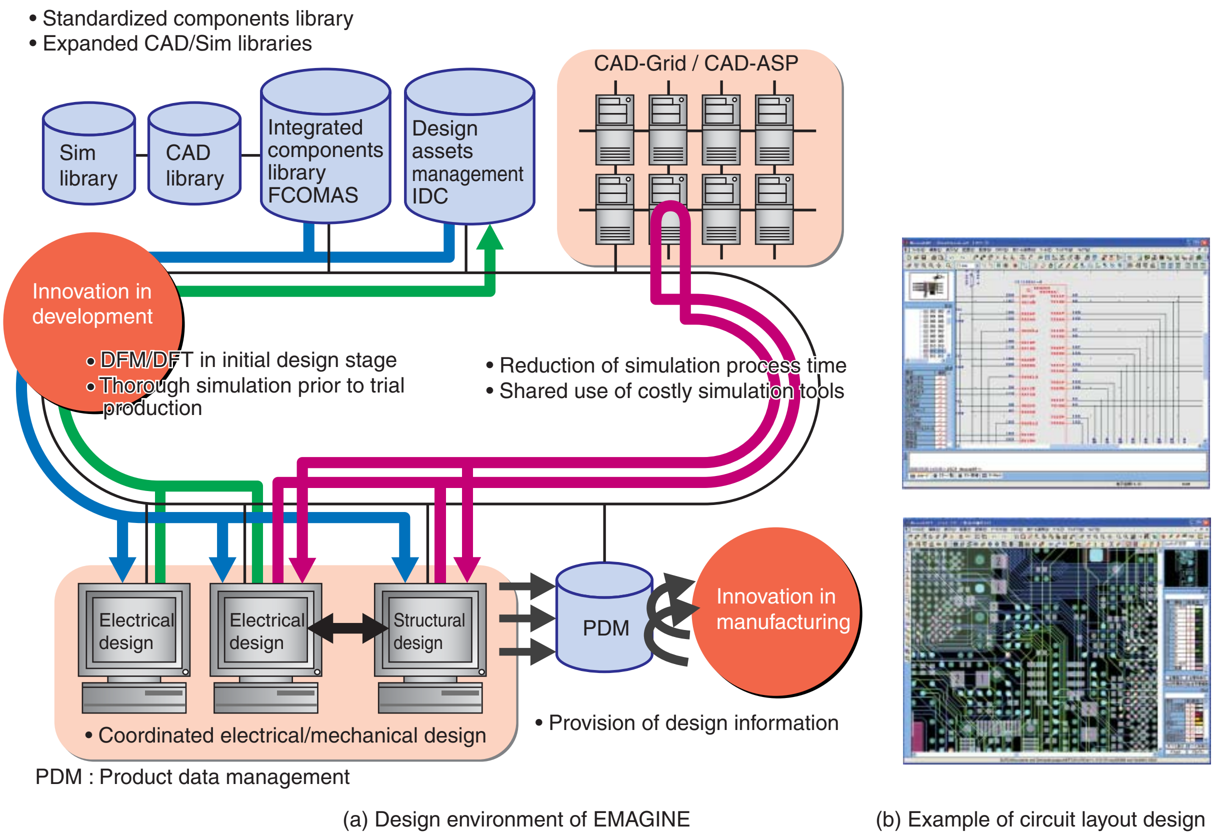


Figure 2
Design environment of EMAGINE and example of circuit layout design.

manufacturability based on rough design data. The results of an examination of the locations of key components, their wiring topology, wiring length, and so forth are transferred to the detailed design stage and thereafter as limiting conditions, which enables the dynamic DRC and navigation designs to be made when designing the layout. Applying CAD tools from the conceptual design stage onwards increases the estimation accuracy and reduces design remakes from the detailed design stage onwards.

3.2 Standardization of components library

The selection of components affects the performance, cost, and life of products. Also, reducing the number of components reduces the stock control costs at the assembly plant, and paying attention to the availability of supply reduces the amount of product redesign in the case of discontinued components. In the last few years, through FCOMAS, Fujitsu has been focusing on reducing the number of standardized components and the provision of component attribute data required for DRC and simulation models with a view to supporting green designs that are free of harmful substances. In EMAGINE, the management of the components library by FCOMAS involves:

1) Dynamic searching and selection of optimum components
2) Standardization recheck of procured components at purchase data output
3) Automatic substitution of discontinued components and components containing harmful substances

3.3 Thorough DFM/DFT from upstream design stages

DFM/DFT aimed at enabling manufacturing and testing to be carried out with ease is thoroughly applied at the detailed design stage to reduce the number of trial production runs as well as the time to mass-production. In order to raise manufacturing yield, it is necessary to develop the design simultaneously with the check of the manufacturing details, for example, the distance of components in consideration of the direction in which solder is applied to the PCB in the solder tank and the soldering heat tolerance of components.

EMAGINE provides automated design and checking for common PCB DFM parameters. In the development of priority devices and products incorporating new technologies, Fujitsu's design and production divisions are engaging in joint activities in which product characteristics and DFM parameters are determined in a planning stage review and incorporated in automatic check parameters.

Further, in PCBs containing ball grid arrays (BGAs), improvements in testing efficiency and fault diagnosis rates are being achieved through efforts to incorporate boundary scan circuits conforming to the Joint Test Action Group (JTAG) standard and installation checks of bonding pads used for testing.

3.4 Coordinated PCB design and structural design

The design of PCBs and the structural design for the mobile terminals and notebook computers they are to be installed in should be coordinated. EMAGINE exports component layout, detailed shape, and height information to structural CAD (hereafter called 3D-CAD) as feedback to devise measures for locations where there is physical interference. In simulations for physical characteristics such as robustness and vibration, Fujitsu engineers with specialist skills provide support in creating high-accuracy models, and analysis times have been shortened through the use of the CAD-Grid environment. Automatic linking of EMAGINE data is also used in the examination of assembly and testing procedures using a Virtual Product Simulator (VPS)[2),3)] and the making of test jigs, resulting in overall optimization in the design of PCBs and the structural design of devices (**Figure 3**).

3.5 Assembly/manufacturing interface

With advances that have been made in technologies and the diversification of manufacturing processes, a wide range of information is needed for manufacturing and assembly processes. EMAGINE sends the design and library information required for each process to the respective manufacturing and assembly plants via an integrated dedicated interface and Fujitsu's in-house WAN. To enhance cooperation between overseas design centers and electronic manufacturing suppliers (EMSs), we are now constructing an industry standard interface that conforms to IPC2511.

4. Noise simulation environment

Simulations can be divided into electrical simulations and mechanical and other physical simulations (hereafter collectively called physical simulations). Typical of the latter are shock, stress, and thermal conductivity simulations. Physical simulations are a highly innovative development tool for the evaluation of product structures, produce designs having excellent shock resistance, and produce component materials having superior thermal conductivity. Physical simulations are described in detail below in the section about applying EMAGINE in product development. In this section, we will focus on electrical simulations regarding signal and power supply noise (hereafter called noise simulations).

With the trend towards higher operating speeds and lower voltages in devices, the design risks have been steadily increasing and it is now harder to suppress noise. For this reason and

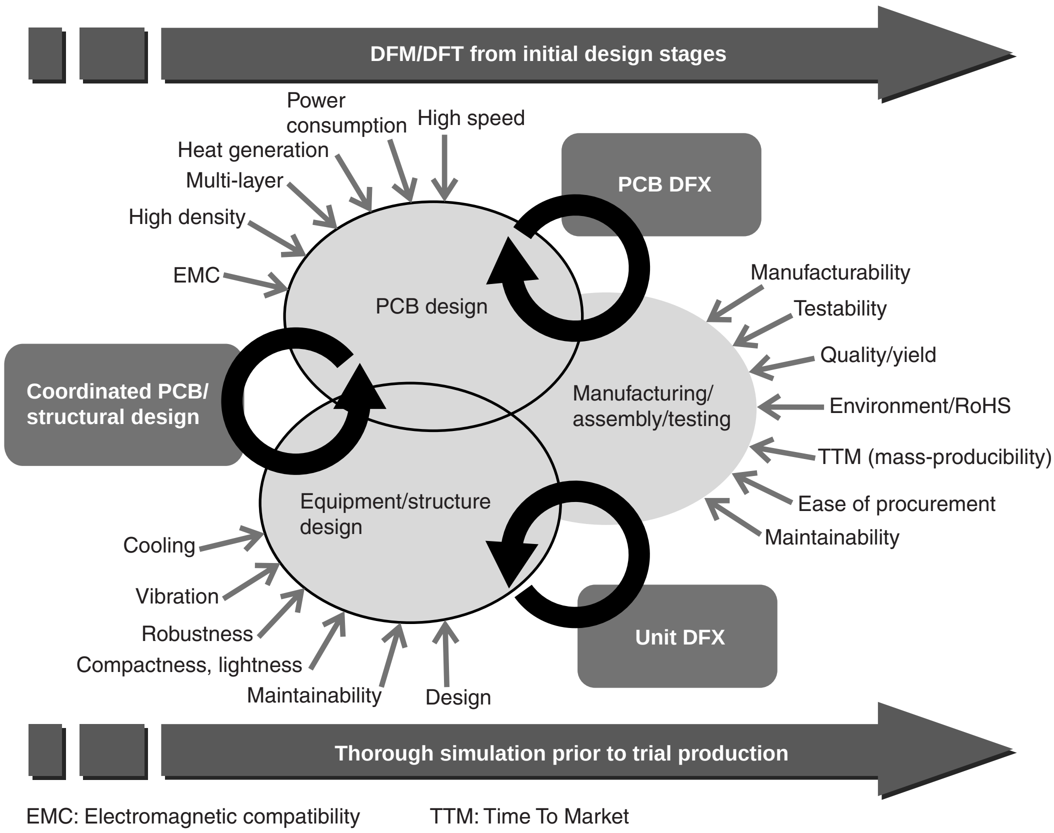


Figure 3
Optimization of total design.

because of the need to shorten development times in order to get products to market as quickly as possible and achieve low cost designs, simulations have become essential at the design stage.[4] It has also become necessary to provide an environment for all design stages that can be used even by inexperienced designers.

In view of this, Fujitsu has made efforts to create a simulation environment for the furthest upstream design stage, circuit design stage, and PCB mounting design stage. We have also made efforts to create an environment that will avoid remakes through joint analysis of PCBs and LSIs at the LSI design stage. Also, electromagnetic interference (EMI) analysis has been linked with our in-house-developed electromagnetic field solver (ACCUFIELD)[5] to create an integrated electrical noise environment that enables high accuracy analysis at the design stage.

Simulation supports innovation in product development. Various simulations are used to complete a product design, and their use in development has produced very good results (**Figure 4**).

Each component of Fujitsu's simulation environment, for example, the circuit simulators, analysis tools, and related elemental technologies, has been developed in-house.

In the creation of our integrated noise simulation environment, we applied the new approach of linking the conceptual design, circuit design, and mounting design stages, which is a departure from the previous approach of alternating between trial production and evaluation. These design stages and their linkage with 3D-CAD are described below.

4.1 Conceptual design stage

At the conceptual design stage, we study the topology of transmitted signals and determine a

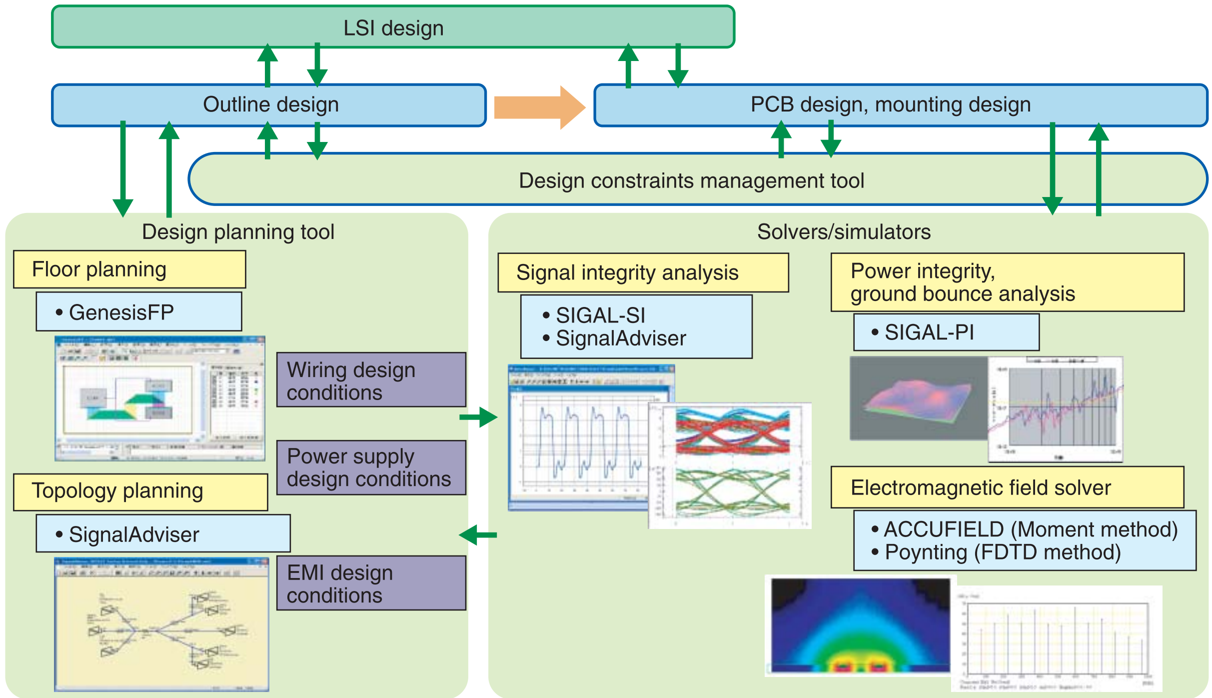


Figure 4
Integrated development system for effective design using noise simulation.

rough image of the populated PCB. Two tools are used for this purpose: GenesisFP, which is a tool for studying floor plans,[6] and SignalAdviser, which is a tool for analyzing transmitted signal waveforms prior to wiring.[6] In the same way a picture is painted on a blank canvas, the designer positions the components and determines the waveform quality by performing a SPICE analysis of the provisional wiring network. Repeating this process several times brings the waveform close to the required quality. SIGAL-PI (a power integrity analysis tool)[7),8] enables the power supply system to be easily evaluated and an approximate rough image of the mounted components to be formed, including the number of bypass capacitors and the mounting position of the on-board power supply (OBP).

In the last few years, eye-pattern analysis, including that for jitter and inter-symbol interference noise, has become a requirement for gigabit transmission in high-speed interconnects. This can be done with SignalAdviser, making it a very valuable tool in the conceptual design stage.

4.2 Circuit design and mounting design stages

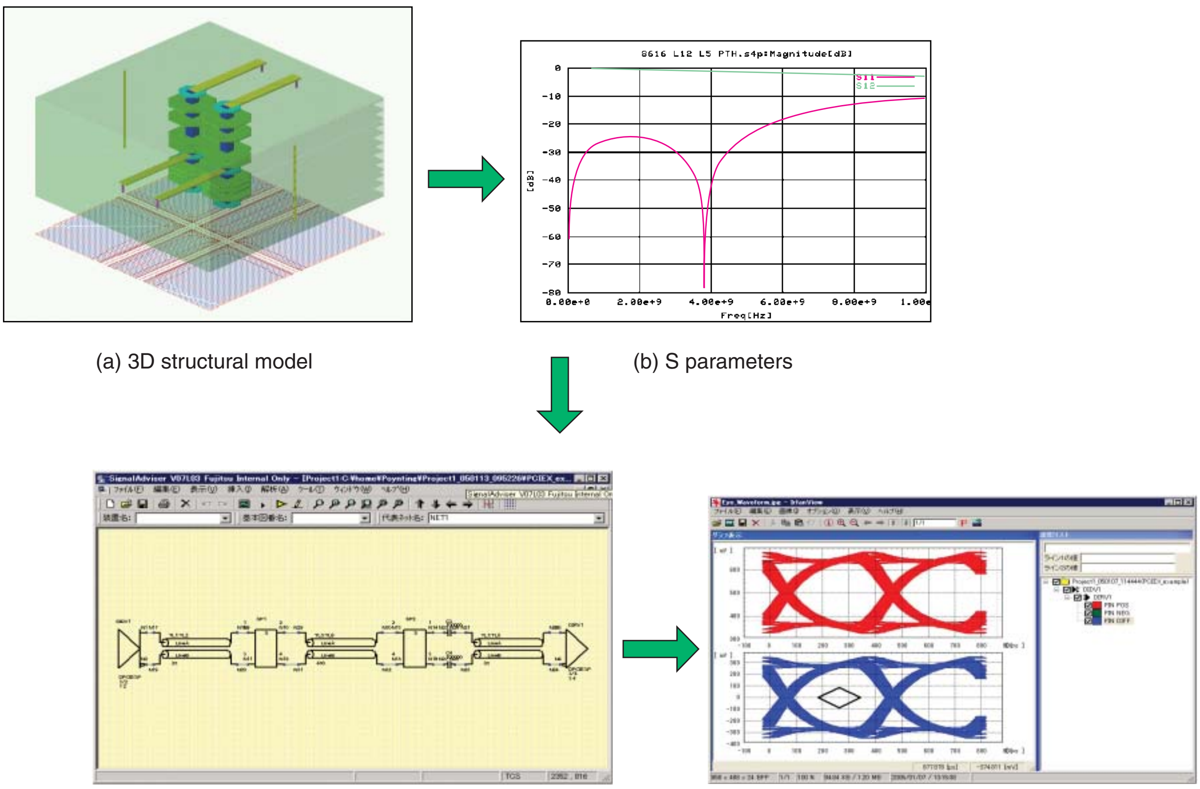
In the circuit design and mounting design stages, the results from the conceptual design stage are carried over and the circuit design for the component layout is studied. This is done in consideration of the loads and topology of the LSIs and with the wiring in place. In the post-wiring analysis at this stage, the use of SIGAL-SI (a post-wiring transmission waveform analysis tool) enables interference, for example, crosstalk between signal lines, to be examined as well as a quality evaluation of timing. With the trend towards higher speeds in recent years, the influence of power supply noise and simultaneous switching noise from LSIs[9),10] is becoming more pronounced. If this noise is not addressed at this stage, when there is a logical image but no prototype, the design will eventually have to be remade. SIGAL-PI easily identifies such problems and greatly helps to avoid them. With ordinary power supply analysis tools, in most cases, LSI power supplies are treated as ideal power supplies in order to study LSIs and PCBs individually. However, because the usage conditions of LSIs are not precisely defined, designs often need to be remade. Because SIGAL-PI analyzes LSIs and PCBs together, many power supply problems can be identified before they occur.

4.3 Linkage with 3D-CAD

To perform as accurate as possible analyses of high-speed interconnect signals, signal transmission routes have to be accurately modeled. Accurate S parameter models can be derived using 3D-CAD and linking with electromagnetic field analysis tools that faithfully reproduce via structures and package shapes. SignalAdviser can perform SPICE model + S parameter analysis with the same degree of accuracy that is achieved using only S parameter analysis (high accuracy but time consuming) and in a shorter time (**Figure 5**).

A major advantage can be gained by knowing the level of EMI that will be produced by a device when it is completed. To achieve this, with ACCUFIELD, we have created an environment that allows EMI from LSIs and PCBs to be easily analyzed at the design stage (Figure 4).

Therefore, through the free use of analysis tools in all design processes, we have been able to identify problems at the design stage and devise optimum solutions for them. The creation of such an environment has greatly contributed to eliminating design remakes and shortening development periods. In the future, we aim to pursue even closer linkages with 3D-CAD in order to create an environment in which electrical



(a) 3D structural model

(b) S parameters

(c) Analysis model

(d) Analysis results

Figure 5
Linkage between 3D-CAD and circuit analysis tools.

and mechanical analysis is highly coordinated.

5. Structural design environment

Although the increased application of 3D-CAD in product development in recent years has led to a marked improvement in design quality, careless mistakes have been made by relying on it too heavily and not fully considering the effects of manufacturing variations and component tolerances.

To be innovative in product development, it is necessary to have a coordinated 3D development environment that pools the knowledge of the various divisions so a higher degree of miniaturization and density can be achieved. In this section, we will discuss an environment for incorporating quality from the upstream design stages, focusing on the CAD-structural design environment.

5.1 Sharing information among divisions connected with product development

As a mechanism for sharing design information from related divisions with a view to enhancing design quality and reducing returns in downstream stages, the system has been arranged so that 3D-CAD data is automatically converted to VPS data and stored in a common server. This allows everyone involved in product development to enhance the quality of design because they can use VPS to reflect requests and comments, for example, those relating to ease of assembly and maintainability, from the various Fujitsu plants at an early stage.

5.2 Verification for manufacturing variations

To make products easy to manufacture, quality engineering must be performed and assembly tolerances must be determined beforehand. However, tolerance analysis tools are not fully used due to the large amount of time required to input and process the limit conditions and other information. The VPS therefore has an automatic clearance checking function that uses gap values. This has enabled most of the tolerance problems that could occur from trial manufacturing onwards to be identified at the design stage. By using this function, designers can concentrate on locations requiring particular attention in tolerance analysis, which has reduced the required number of person-hours and raised the quality of design (**Figure 6**).

5.3 Linkage with PCB design

By unifying the various CAD data for PCBs and mounting structures in a VPS, we have created an environment in which interference, including that of PCBs, can be verified in a single operation. This environment comprises conventional conversion technology for PCBs and mounted components and also converts wiring patterns (lands and lines) and other features into 3-D models. Until now, this conversion created several 10s of gigabytes of data, which is too much to be handled on a PC. However, through stratification and shape simplification, this has been reduced by more than 90%. As a result, the check for short circuits between metal components and PCBs can be rapidly and automatically performed, which was previously not possible.

5.4 Linkage with analysis simulation

Physical simulations are often conducted alongside product design using 3D-CAD; however, for complex product shapes, a very large number of analysis meshes are required, which extends the analysis calculation time. To overcome this problem, the analysis is usually performed on simplified models. However, this means designers have to modify both the product model and the analysis model, which reduces design efficiency. Therefore, as shown in **Figure 7**, we developed a VPS function that removes the fine details from the 3D data in a single operation. This has halved the time needed to make analysis models and has helped

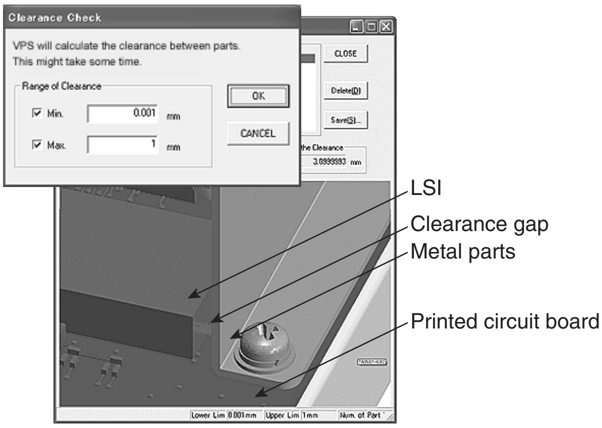


Figure 6
Clearance check.

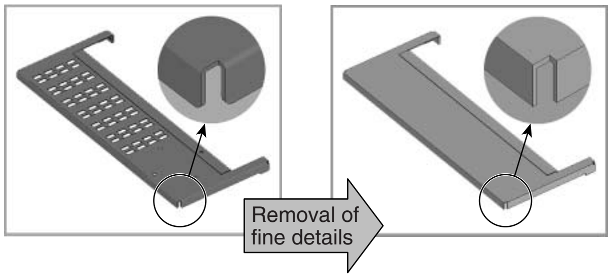


Figure 7
Automatic removal of fine details to simplify analysis.

enhance design quality, starting from the upstream stages.

5.5 Other linkages

Three-dimensional CAD data has also been widely used in linkages with life-cycle assessment (LCA), environment design, and CAM. For instance, it has enabled person-hours to be reduced in manufacturing design and manufacturing preparations (the latter achieved by providing easy-to-understand assembly instructions using videos) and to provide our Recycle Center with dismantling instructions.

6. Conclusion

In this paper, we have described the Fujitsu Group's integrated design environment, which raises the quality of design by coordinating divisions concerned with product development from the upstream stages of the design process. Creating such an environment has raised efficiency by providing CAD libraries and developing new functions for electrical design, simulation, and structural design. It has also made product development more effective by enhancing quality in the upstream stages and reducing design remakes through the promotion of overall optimization, for example, by integrated verification achieved by sharing information among divisions.

In the future, we will make efforts to further reinforce the design environment by reflecting the requests of Fujitsu's design and manufacturing divisions for the strengthening of verification functions specific to products under development as well as through further linkages.

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